Mars Exploration Program

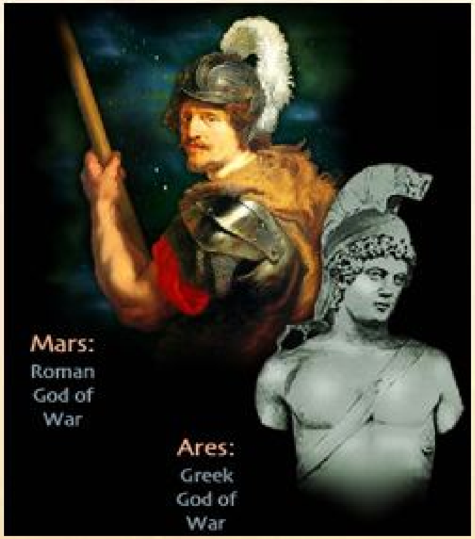
Doug McCuistion, Director

1 December 2006

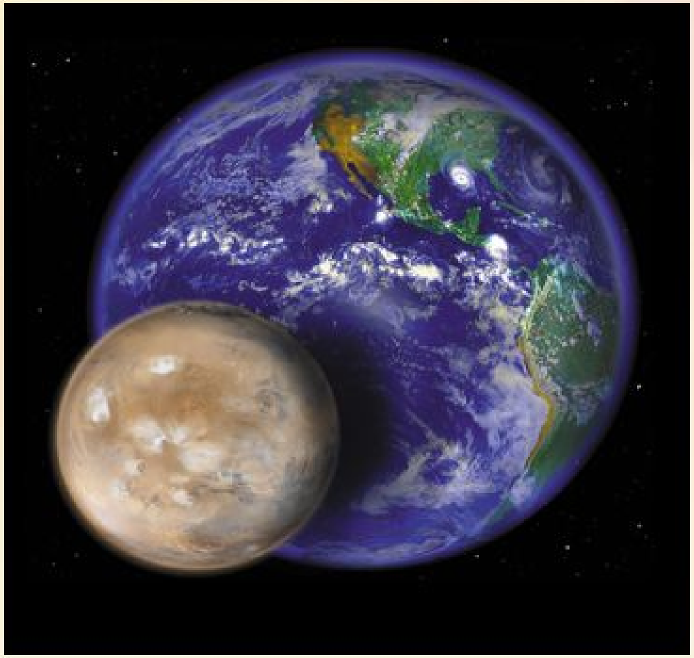
"Those who labor over robotic missions are some of the great explorers of our times, even though their feet never tread the soil of another world"

National Academy of Science "Assessment of NASA's Mars Architecture 2007-2016"

Why Mars?



- A tangible frontier that has captivated human's curiosity, imagination, and the spirit of exploration for ages
  - Mars has had and will continue to have special appeal to the public.
- Mars is the most easily accessible body that has the potential to answer all four key research objectives of the Planetary Science Division:
  - Learn how the Sun's family of planets and minor bodies originated and evolved
  - Understand the processes that determine habitability in the solar system, including the Earth's biosphere and Mars.
  - Identify and investigate past or present habitable environments on Mars and other worlds.
  - Discover potential hazards to humans, and search for resources.
- It is the only planetary body that for which we can realistically assess biological potential, and life
  - Early Mars preserves a record of conditions and materials from which life could have started on Mars or on Earth
  - Even today there are places on Mars that could be "habitable"
- Mars accessibility permits frequent and iterative exploration.
  - Allows for an integrated and sustainable program, providing feedback affecting subsequent missions in science and engineering.
- Mars is specifically targeted in our nation's Vision for Space Exploration.



Mars is a Nationally Recognized Priority

and High Priority for the Agency

NASA Advisory Council Planetary Science Subcommittee

Within solar system exploration, Mars is the highest priority target for detailed investigation

- *The ability to address all 4 research objectives at Mars, coupled with its accessibility, make Mars a unique scientific target in the solar system.*
- *Mars exploration has progressed to the level where scientific investigations require multiple assets that form a temporally and spatially interrelated infrastructure on the surface and in orbit.*
- *Mars is specifically called out as a high priority target in the VSE.*

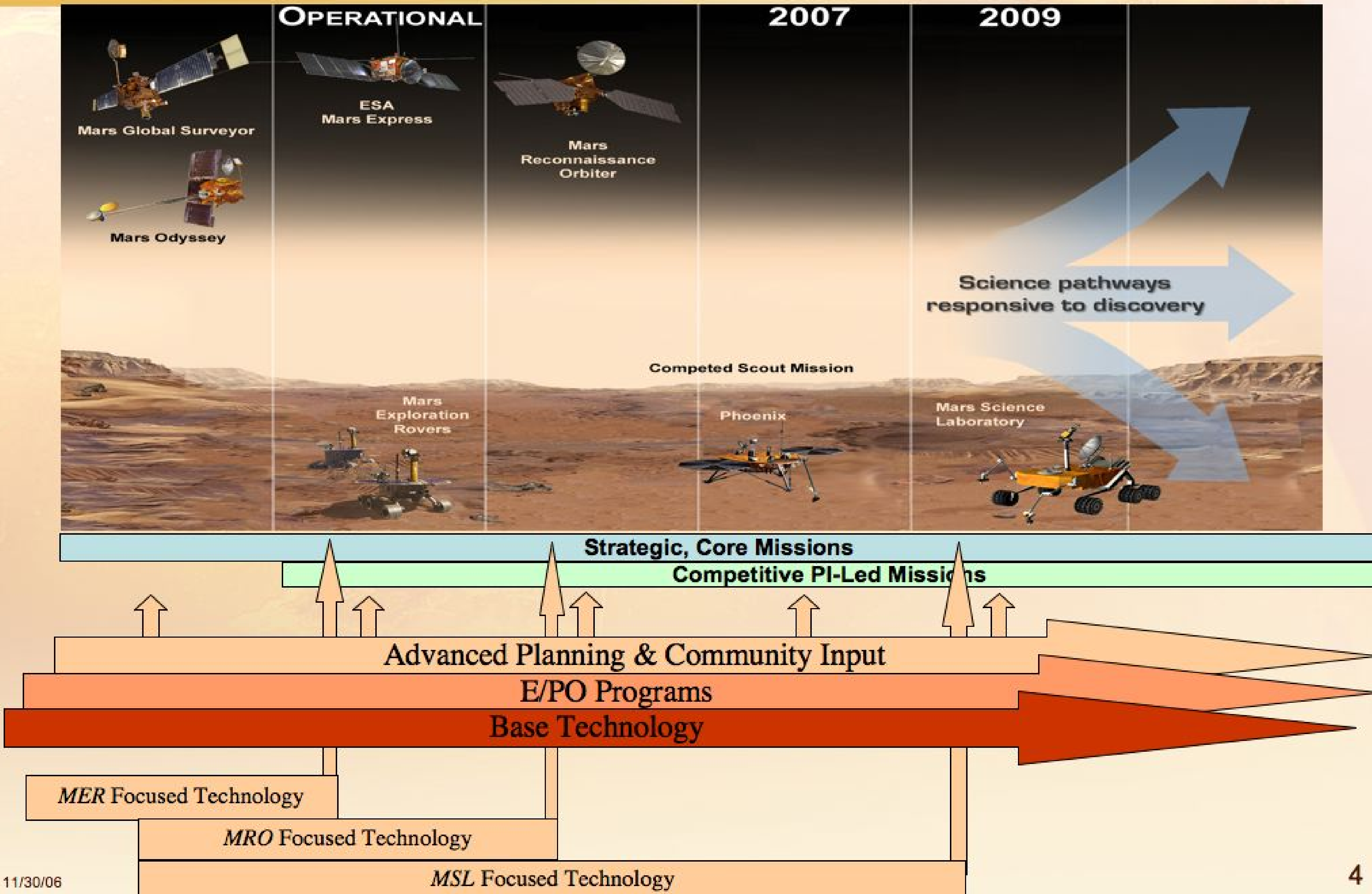
National Research Council

"The decadal survey envisions a very active and balanced Mars Exploration Program that would substantially contribute to an integrated understanding of the formation and evolution of the solar system."

The Vision for Space Exploration

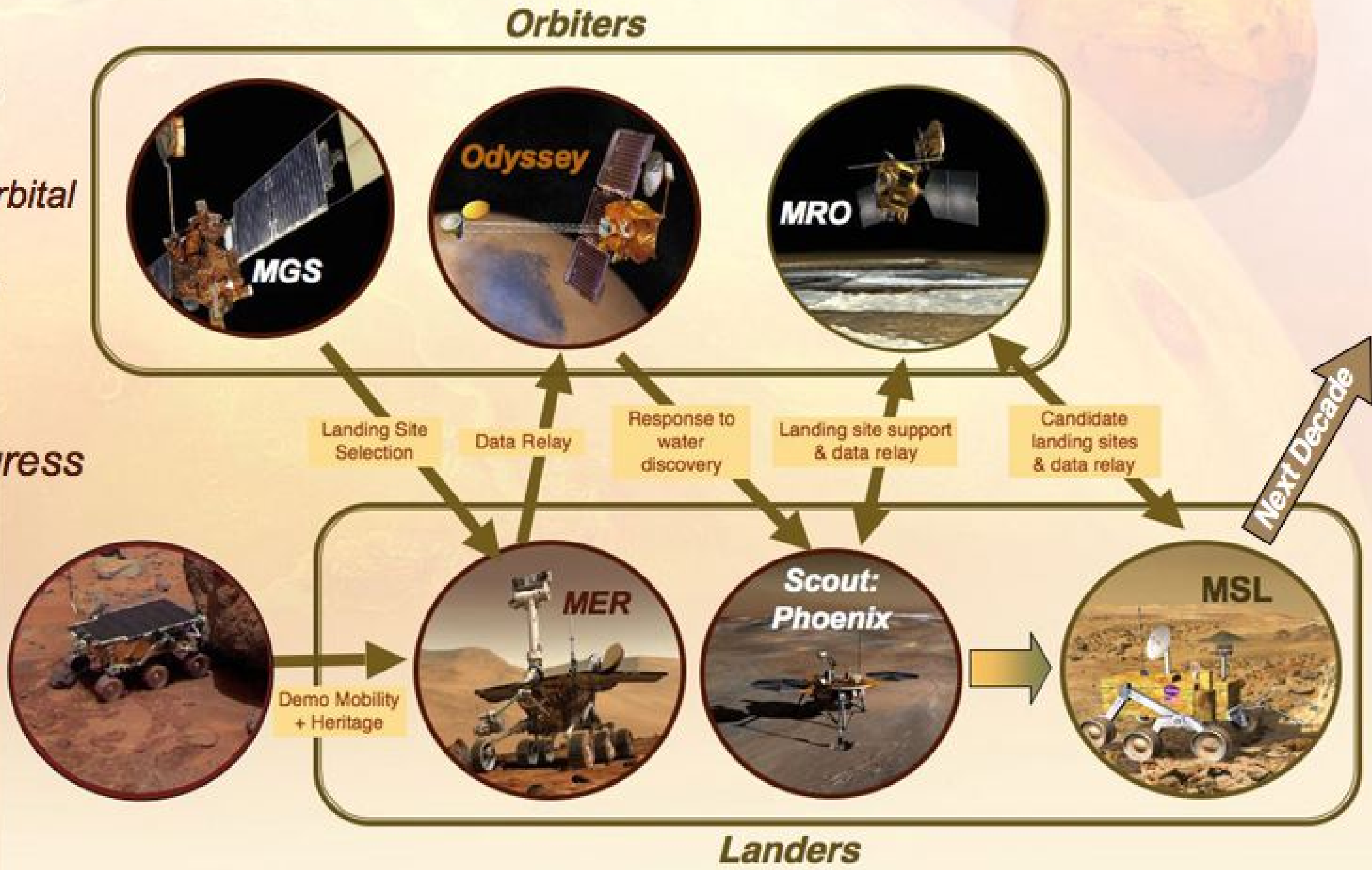
"The timing of the first human research missions to Mars will depend on discoveries from robotic explorers, the development of techniques to mitigate Mars hazards, advances in capabilities for sustainable exploration, and available resources."

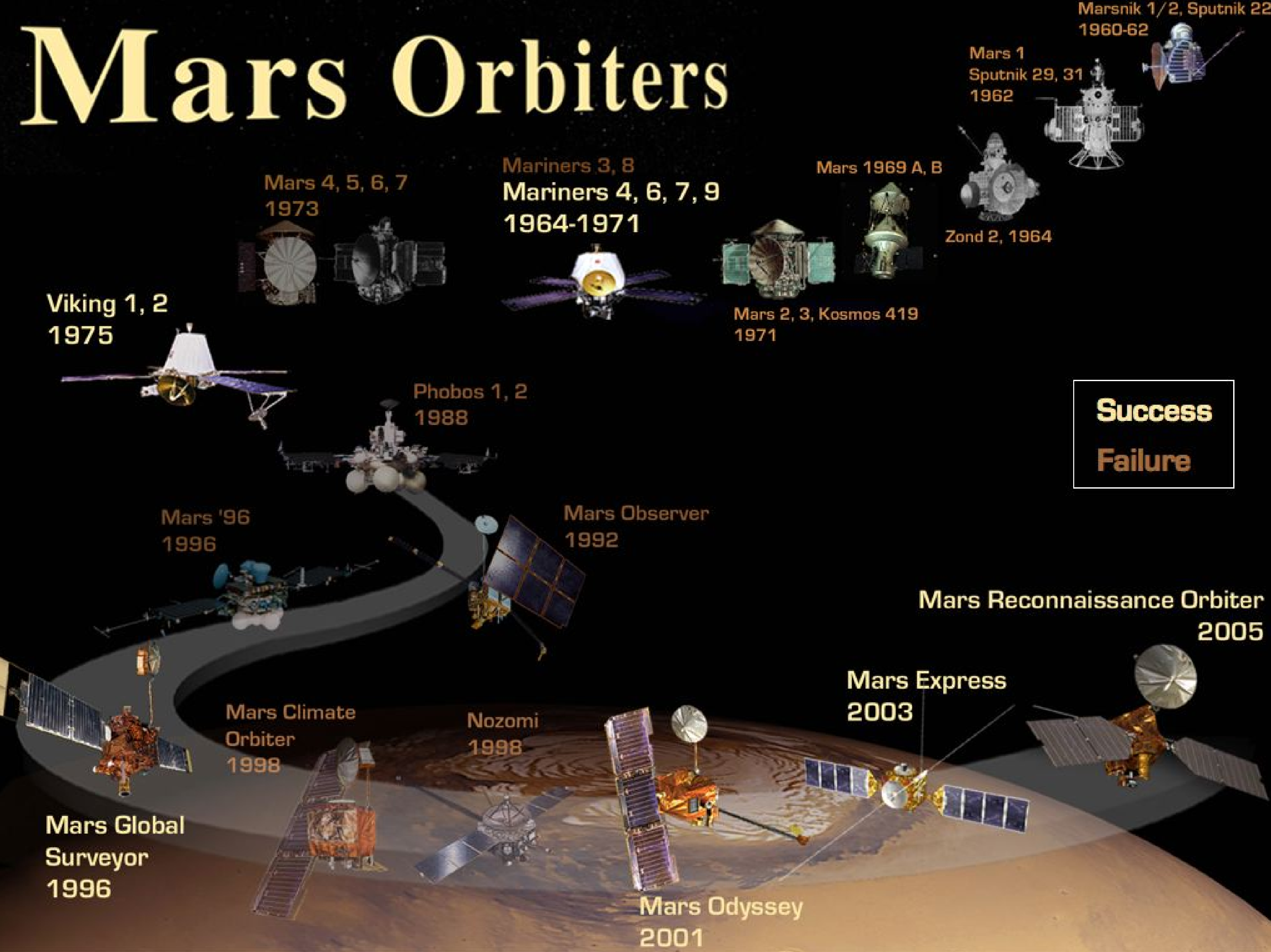
MEP—An Integrated Set of Activities Creating a True Program Structure



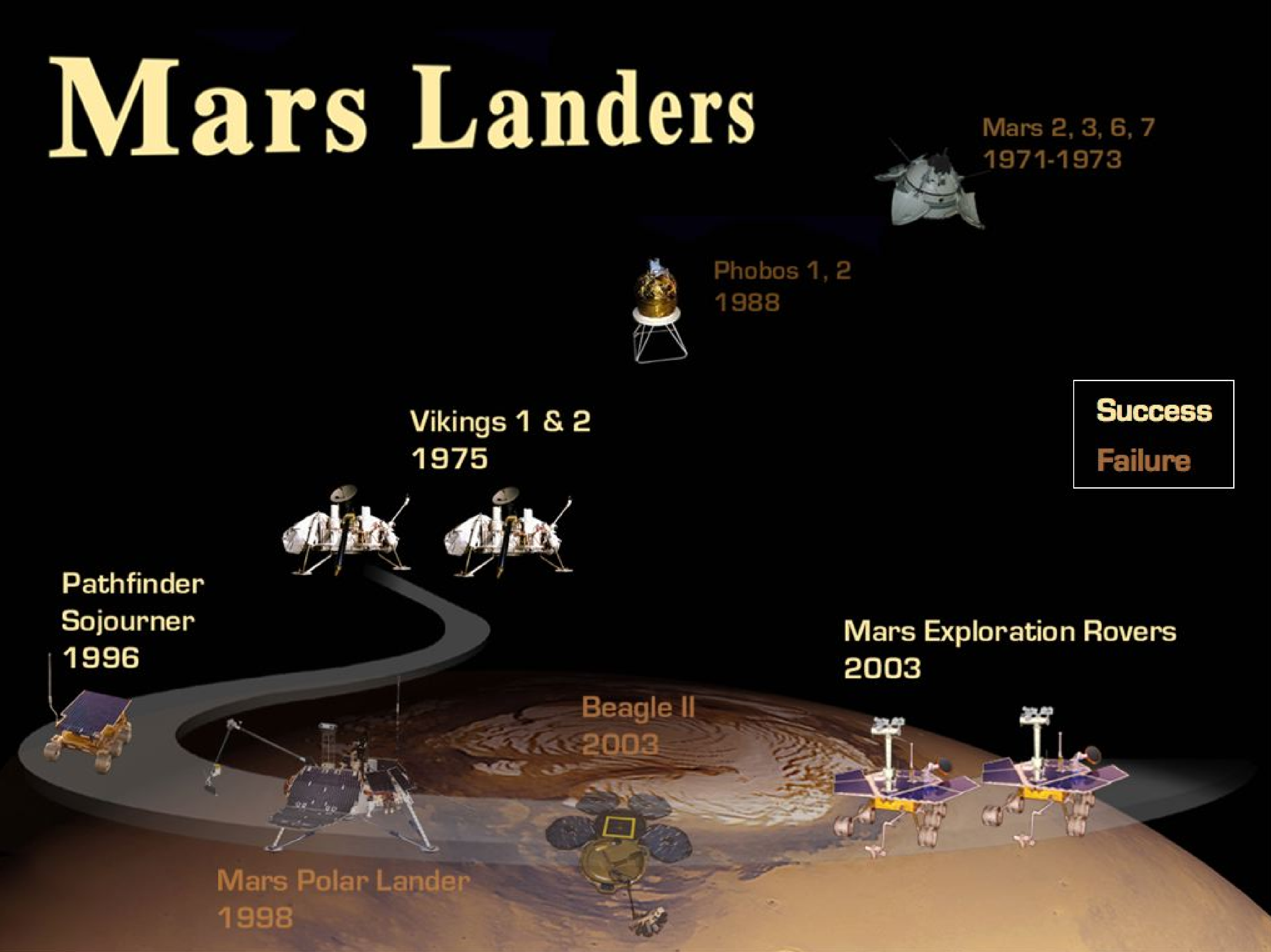
Detailed Exploration Requires a Long-term Program Approach

- *Support key science strategies and goals*
  - *Intensive investigation requires flight at every opportunity*
  - *Integrated surface & orbital assets*
  - *Aligned Research and Analysis Programs*
- *Provide technology progress and infusion*
  - *Supports evolving capabilities*
- *Sustain a supporting infrastructure*
- *Management structure that supports integration of assets and requirements*





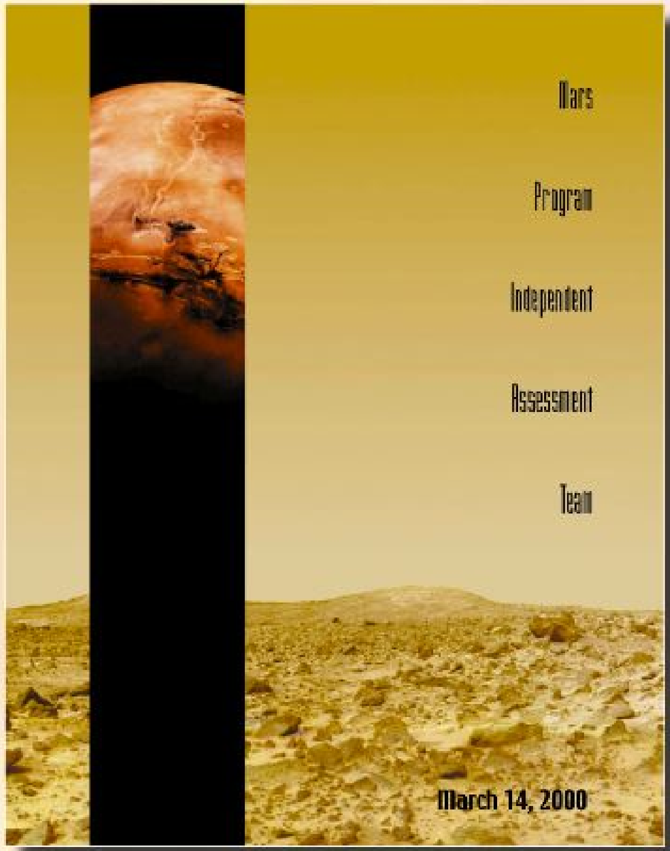
Mars Orbiters
Marsnik 1/2, Sputnik 22
1960-62
Mars 1
Sputnik 29, 31
1962
Zond 2, 1964
Mars 1969 A, B
Mars 2, 3, Kosmos 419
1971
Mariners 3, 8
Mariners 4, 6, 7, 9
1964-1971
Mars 4, 5, 6, 7
1973
Viking 1, 2
1975
Phobos 1, 2
1988
Mars Observer
1992
Mars '96
1996
Success
Failure
Mars Reconnaissance Orbiter
2005
Mars Express
2003
Mars Climate
Orbiter
1998
Nozomi
1998
Mars Global
Surveyor
1996
Mars Odyssey
2001



Mars Landers
Mars 2, 3, 6, 7
1971-1973
Phobos 1, 2
1988
Success
Failure
Vikings 1 & 2
1975
Pathfinder
Sojourner
1996
Mars Exploration Rovers
2003
Beagle II
2003
Mars Polar Lander
1998

The Mars Exploration Program Historical Context

- *Mars Surveyor Program established in 1994*
- *Mars Pathfinder and meteorite ALH84001 revealed extensive public interest*
- 1999 failures of Mars Climate Orbiter and Mars Polar Lander led to Review
  - The "Young Report", Mars Program Independent Assessment Team (MPIAT)
- Restructuring of Mars program in 2000 established the principles and strategy for this decade of missions:
  - Current Program structure
    - 2001-2009 Mission Architecture
  - Clear lines of authority
  - Current management practices
    - Early definition and stability of Project requirements
    - Early assessment of mission risks and effective risk management
    - Technical/Financial margins commensurate with risk
    - Comprehensive independent reviews
    - Continuity of management/personnel from development to operational phases
- These principles and practices have withstood the test of time—based on success to-date



Goals, Objectives, Requirements Structure

- *At the top level, the Program is driven by 2 types of Program Goals*
  - *Scientific Goals*
    - *Driven by National Policy (the Vision), the NASA Strategic Plan, SMD Science Plan, and community input (the National Academies, Mars community, NASA Advisory Council), etc.*
  - *Programmatic Goals*
    - *Derived from NASA policy and procedure (e.g. NPDs), SMD policy (e.g. Science and Strategic Plans), and national policy (e.g. the Vision)*
    - *Developed to enable accomplishment of the Scientific Goals*

- *Derived elements "under" the goals include:*
  - *Scientific Objectives*
  - *Programmatic Objectives*
  - *Program-level Requirements flow from goals and objectives, and include:*
    - *PCA Technical Commitments*
    - *Program-derived, top-level requirements*

Programmatic Goals

- *Maintain a continuous operational presence at Mars*
  - *Operating orbiters or landers*
  - *Provide telecommunications relay capability*

- *Launch at least one mission to Mars at each 26-month opportunity*

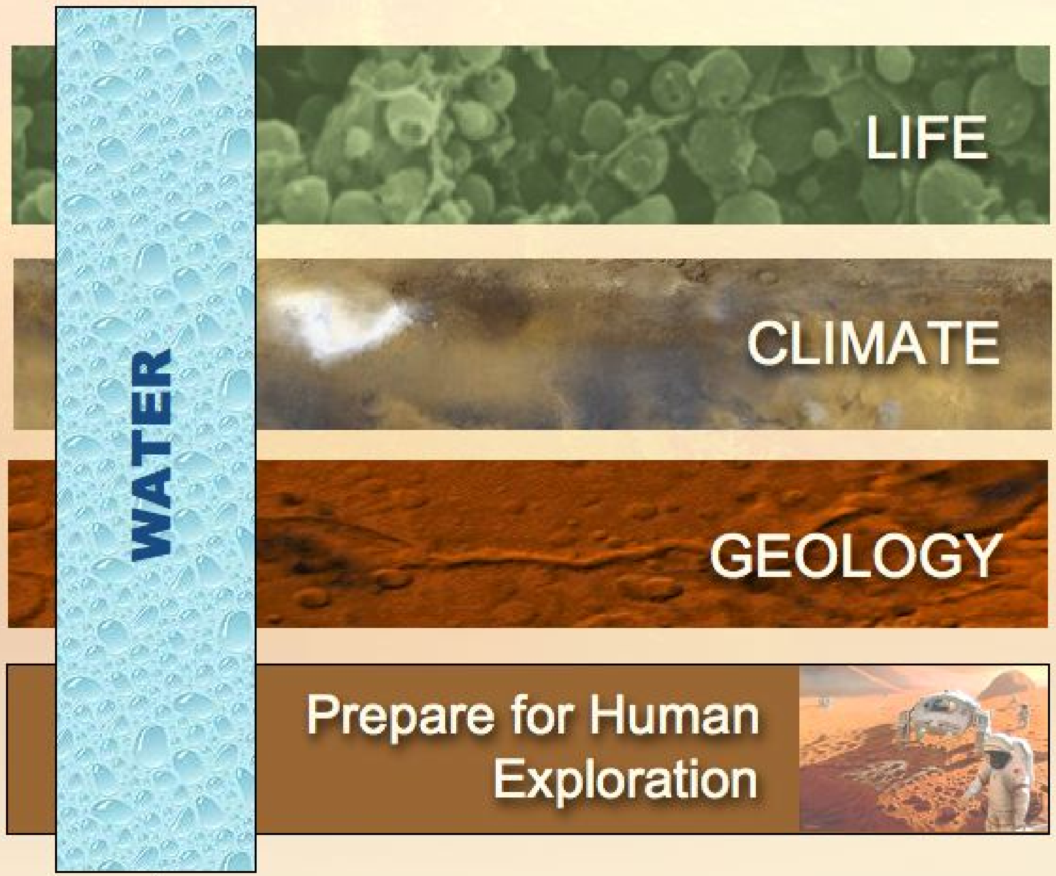
- *Provide continuing improvements in technical capabilities of Mars missions by investments in technology development*
  - *Conduct a technology investment program*
  - *Investment goal of 5-10% of the overall MEP budget.*

- *Capitalize on measurement opportunities that contribute to the advancement of knowledge required for future human exploration of Mars, in collaboration with ESMD.*
  - *Consider scientific measurements and technologies that can enable human exploration of Mars*
  - *Exploit relevant data*
  - *Fly instruments of opportunity from ESMD on a mutually agreed-to basis.*

- *Ensure that Mars exploration activities will be publicly engaging and will contribute to NASA's education strategies*
  - *Conduct an exciting education and public outreach program*

The Mars Science Strategy: "Follow the Water"

A science-driven effort to characterize and understand Mars as a dynamic system, including its present and past environment, climate cycles, geology, and biological potential.



Understand the potential for life elsewhere in the Universe

Characterize the present and past climate and climate processes

Understand the geological processes affecting Mars' interior, crust, and surface

Develop Knowledge & Technology Necessary for Eventual Human Exploration

When • Where • Form • Amount

Each Science Goal has Underlying Scientific Objectives

- **Goal – Life:** *Determine if life ever arose on Mars*
  - *Assess the past and present habitability of Mars*
  - *Characterize carbon cycling in its geochemical context*
  - *Assess whether life is or was present on Mars*

- **Goal – Climate:** *Understand the processes and history of climate on Mars*
  - *Characterize Mars' atmosphere, present climate, and climate processes*
  - *Characterize Mars' ancient climate and climate processes through study of the geologic and volatile record of climate change*
  - *Characterize the state and processes of the Martian atmosphere of critical importance for the safe operation of spacecraft*

- **Goal – Geology:** *Determine the evolution of the surface and interior of Mars*
  - *Determine the nature and evolution of the geological processes that have created and modified the Martian crust and surface*
  - *Characterize the structure, composition, dynamics, and evolution of Mars' interior*

- **Goal – *Prepare for Human Exploration***
  - *Obtain knowledge of Mars sufficient to design and implement a human mission with acceptable cost, risk and performance*
  - *Conduct risk and/or cost reduction technology and infrastructure demonstrations in transit to, at, or on the surface of Mars*

MEPAG (2006), Mars Scientific Goals, Objectives, Investigations, and Priorities: 2006, J. Grant, ed., 31 p. white paper posted February, 2006 by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/index.html.

Community Input and External Advice to MEP

Community Input

- *The Mars Exploration Program Analysis Group (MEPAG)*
  - *Self-identified scientific community interested in Mars exploration*
  - *Executive Committee for planning MEPAG meetings and commissioning Science Analysis Groups*
  - *Chair is member of the Planetary Science Subcommittee*

NASA Advisory Council

- *Planetary Science Subcommittee*
  - *Advise on scientific and programmatic priorities for Planetary Science*
- *Planetary Protection Subcommittee*
  - *Advise on planetary protection requirements for missions*

NASA Advisory Structure

NASA Advisory Council

Science Committee

Planetary Science Subcommittee

Mars Exploration Program Analysis Group (MEPAG)

Federal Science Advisory System

National Academy of Science

NRC

Space Studies Board

Committee on Planetary and Lunar Exploration

National Research Council

- Committee on Review of Solar System exploration including Mars
  - Decadal Survey
  - Special assessments on request
  - Planetary Exploration (COMPLEX)
  - Committee on Origin and Evolution of Life (COEL)
- Astrobiology Strategy for Mars Exploration (commissioned study)

Mission Classes

Fair and Open Competition: Instruments and/or Missions

- ***Strategic Missions***
  - Strategic missions are required to accomplish the scientific goals and objectives defined by the Agency and Program—assigned to a NASA Center
  - *Mars community to analyze benefits & feasibility of mission possibilities*
  - *Science Definition Team (SDT) – HQ commissioned group to develop mission goals, characteristics, and strawman payload*
  - *Competitive selection of investigations (with instruments and/or spacecraft bus) addressing the goals defined by the SDT*

- ***Mars Scouts***
  - Missions that are complementary to the Strategic Mission line, that also provides quick-reaction research responding to discoveries
  - *PI led missions (PIs proposing to meet science goals)*
  - *Every 2 or 3 launch opportunities*
  - *Announcement of Opportunity (AO) selection process*
  - *9-month Phase A for down-select*
  - *May include competition for "Mission of Opportunity"*

MEP International Partnerships

- *MEP is continuously exploring, entertaining, and encouraging international participation in Mars exploration*
  - *There is a vibrant, healthy interest internationally in Mars Exploration*
  - *Every NASA Mars mission has international collaboration*

- *International cooperation is typically undertaken on a no-exchange-of-funds basis.*

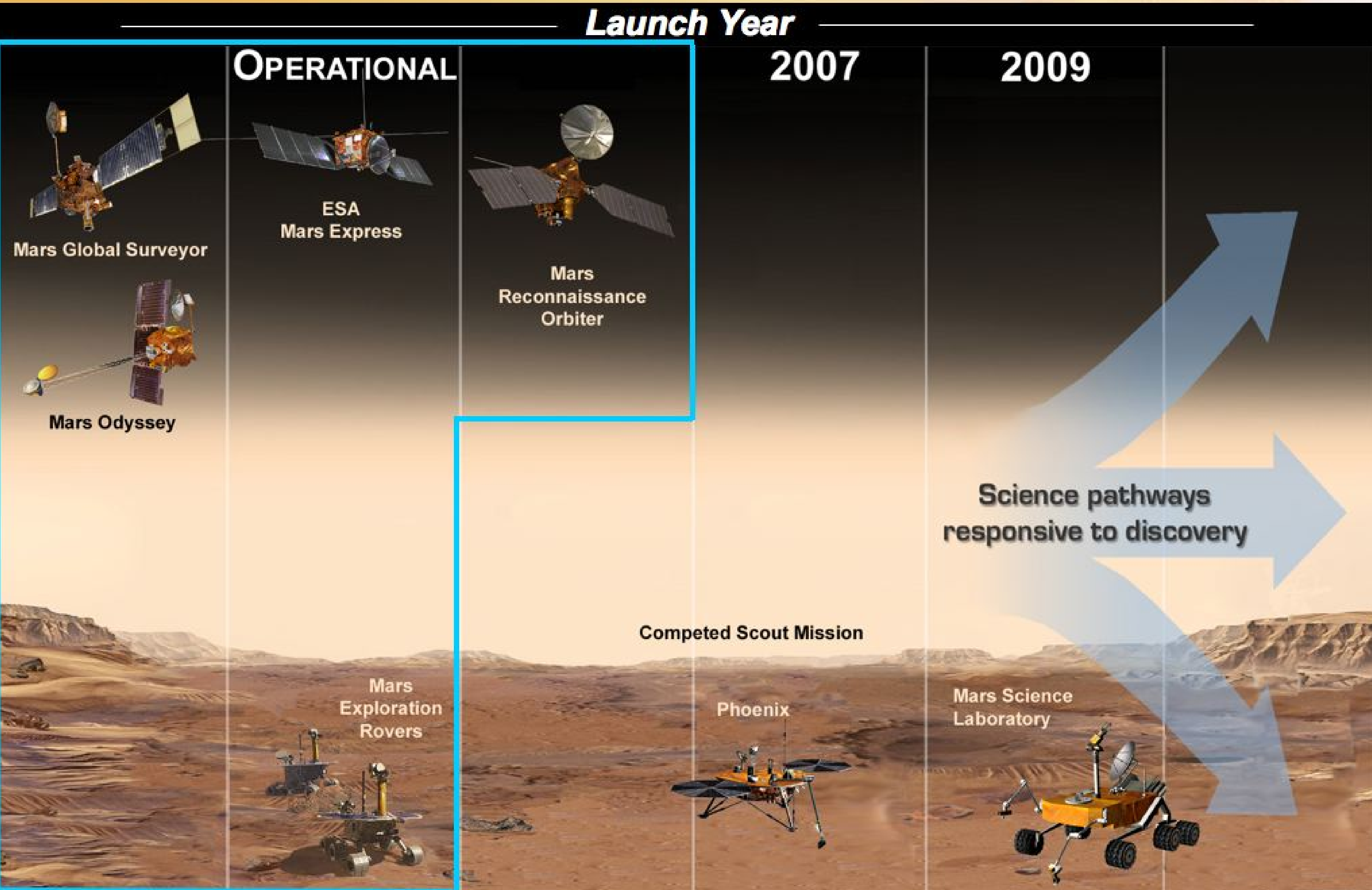
- *Cooperation can be competed or strategic:*
  - *Foreign partners are routinely selected through NASA competitive Announcements of Opportunity for contributed instrumentation and science.*
  - *At times, it may be in NASA's interest to seek a strategic partnership as a means to combining financial resources; gaining access to unique foreign capabilities, expertise, or geography; increase the mission flight opportunities; enhance the scientific return; or promote U.S. foreign policy interests.*

- *NASA cooperates in planning missions through:*
  - *International Mars Exploration Working Group (IMEWG)*
  - *Multi- and bi-lateral agreements and studies*

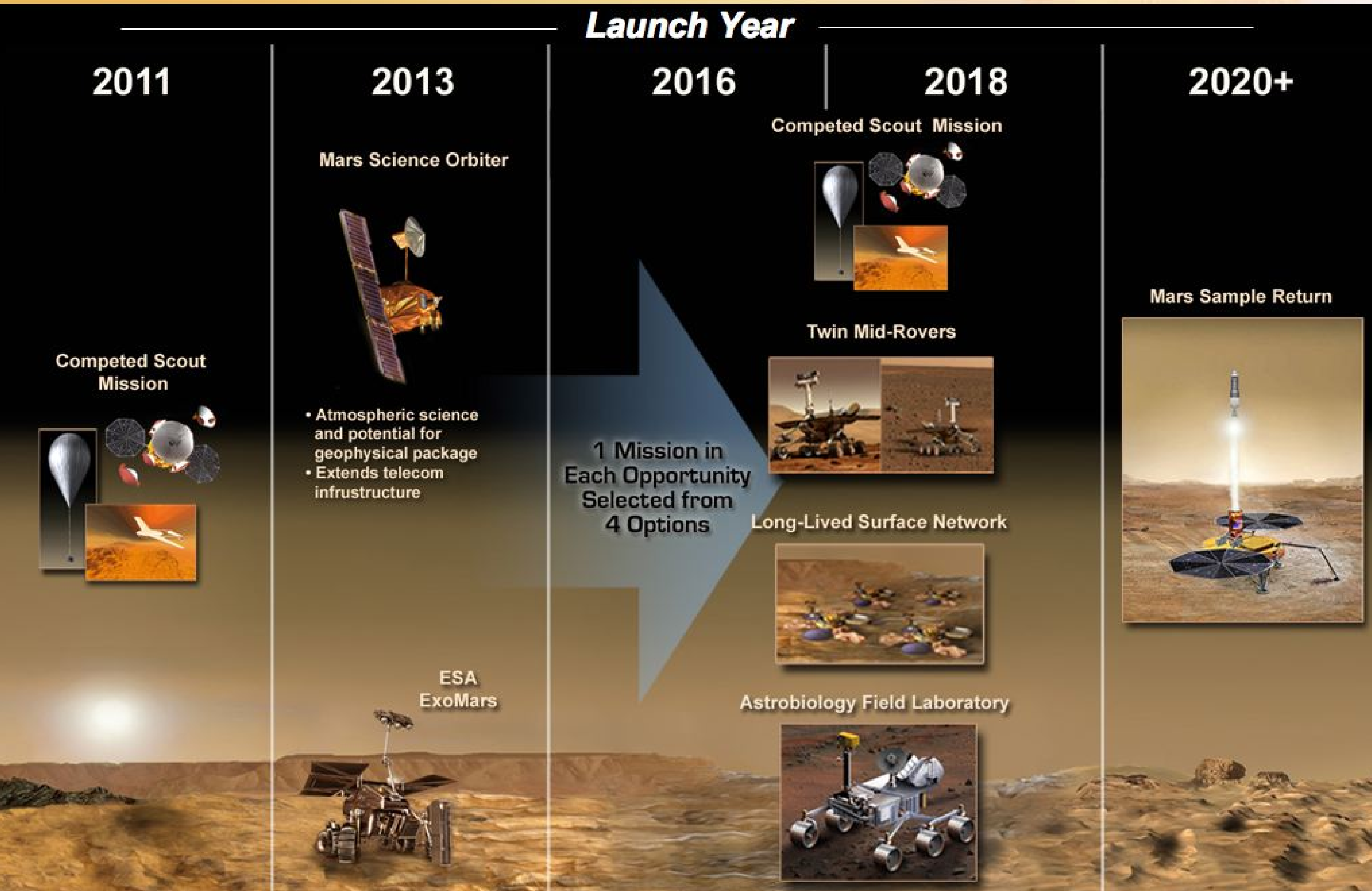
- *Management of mission risk due to dependencies is managed on a case-by-case basis*

The Mars Exploration Program

The Current Decade



Mars Program Architecture: Next Decade



Missions

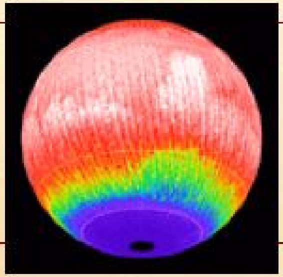
Mars Global Surveyor-1996

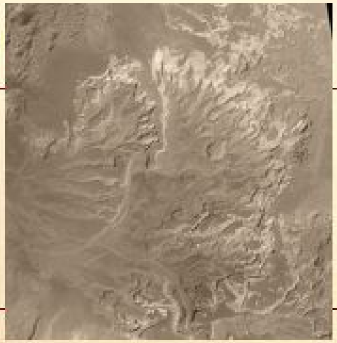
Salient Features

- Global mapping of Martian atmosphere, surface, magnetic field
- Nadir pointed spacecraft
- 5 instruments (MOC imager, MOLA laser altimeter, TES - IR spectrometer, MAG magnetometer, RS radio science)
- Launch date: November 1996
- Mapping lifetime: One Mars year (687 days)

Status

Last confirmed contact with MGS was Nov. 2. Attempts to image with MRO and communicate through MER have been unsuccessful.





Science

- *Thermal Emission Spectrometer mapped Martian minerals revealing a diverse volcanic history and found the first evidence of an aqueous mineral, hematite, in the region of Meridiani Planum*
- *Mars Orbiter Camera revealed: extensive layering deep into the Martian crust; deltas, at Eberswalde and Holden Crater, evidence of long-standing bodies of water into which water persistently flowed; and thousands of gullies, evidence that water had flowed on the surface of Mars in the recent past.*
- *Mars Orbiter Laser Altimeter mapped global topography. The characterization of the volume and vertical structure of the permanent polar caps on Mars show they are predominantly made of water ice (and not CO_2 ice)*
- *Magnetometer found remnants of an ancient magnetic field, indicating that Mars had a protective magnetic field early in its history.*

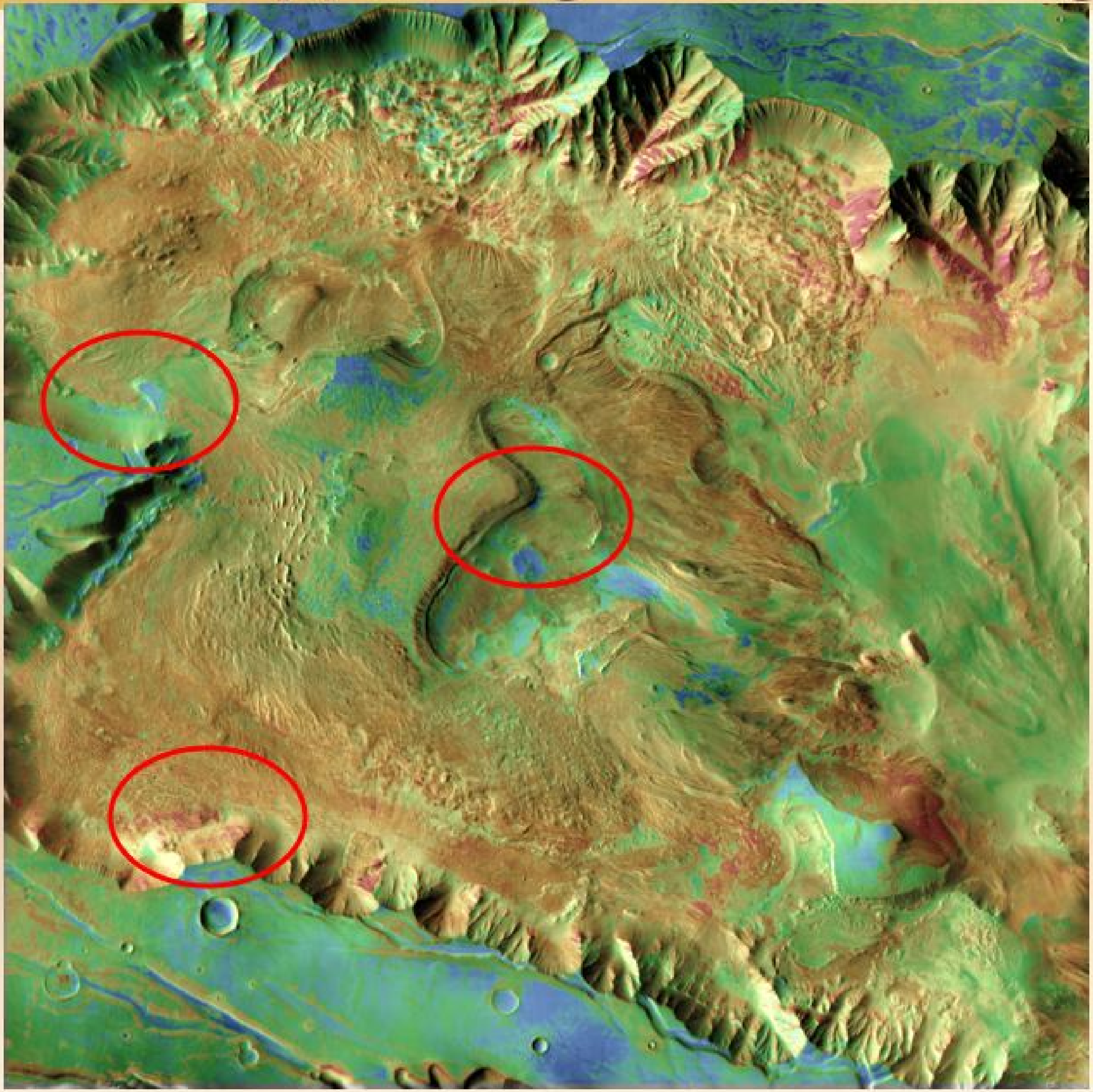
Mars Odyssey - 2001

Salient Features
- Mars Orbiter Launched: April 7, 2001
- Payload: GRS, THEMIS, MARIE
- Primary Mission: Feb 19, 2002 - Aug 24, 2004
- Extended Mission: Aug 2004 - Sep 2006

Status
- THEMIS
  - Excellent health with nominal performance
  - 99.9% of surface mapped in infrared, 44.6% mapped in visible
- GRS Suite (GRS, NS, HEND) - Excellent health with nominal performance
- MARIE - Non-functional since October 2003

Science
- Globally Map the Elemental Composition of the Surface.
- Acquire High Spatial and Spectral Resolution Mapping of Surface Mineralogy.
- Determine Abundance of Hydrogen in the Shallow Subsurface.
- Provide Information on the Morphology of the Martian Surface.
- Characterize Specific Aspects of the Martian Near-Space Radiation Environment.
- Observing inter-annual variations and secular changes

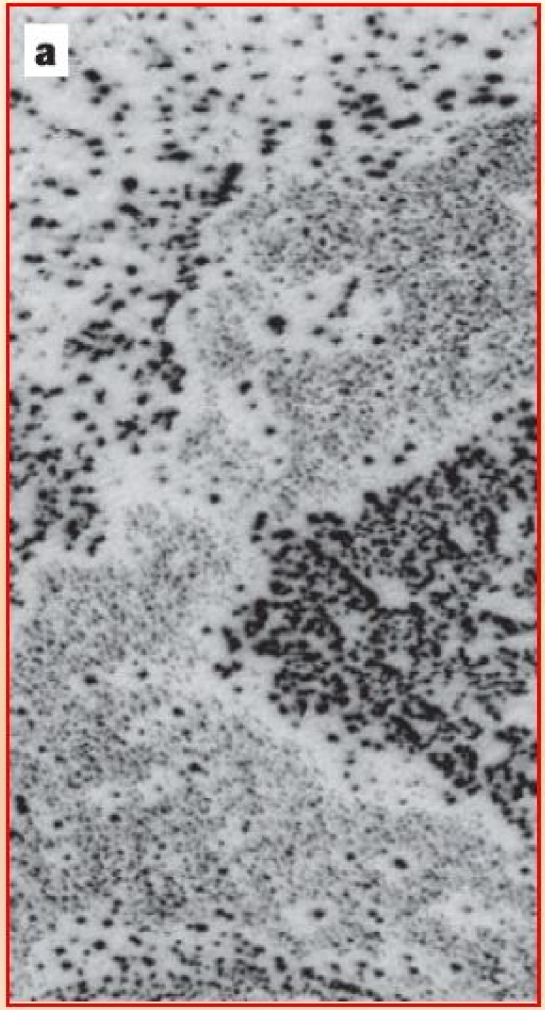
THEMIS: Supporting MSL Landing Site Selection

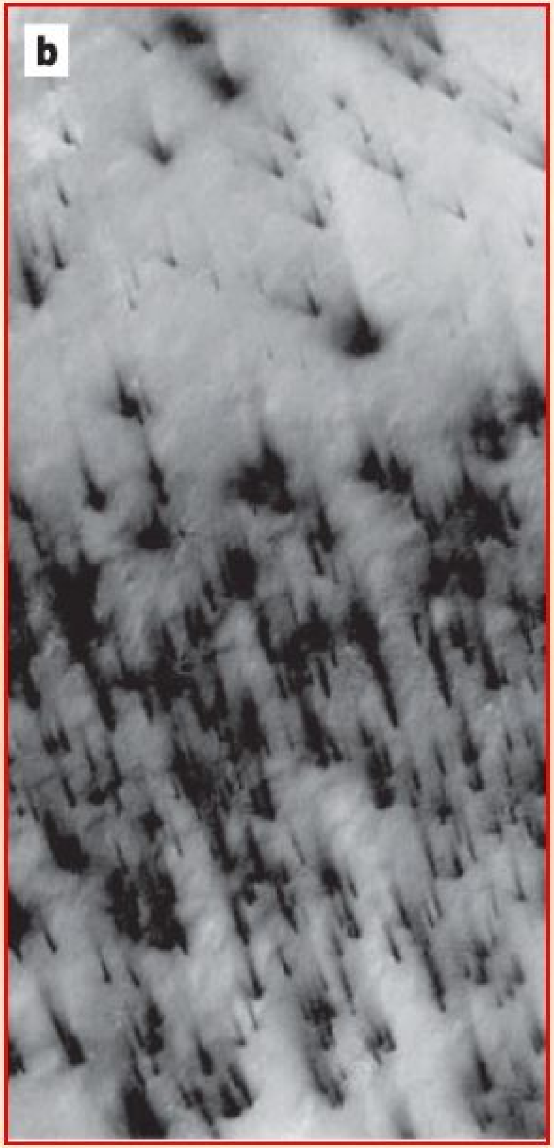


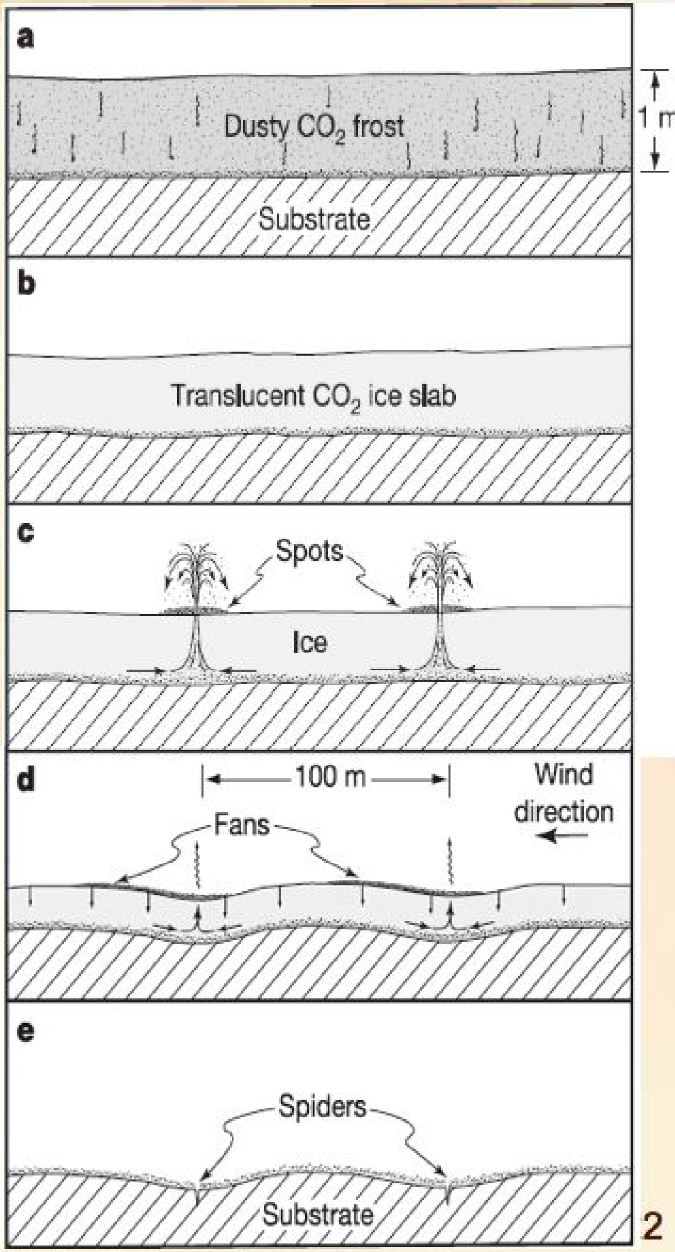
<u>Western Candor Chasma</u>

- 1 of 33 sites under consideration for MSL
- Area has interior layered deposits
- OMEGA has found evidence for hydrated sulfate minerals and kieserite (a magnesium sulfate). Water plays an extensive role in their formation.
- THEMIS false color IR, 100 m resolution

Odyssey
Spots, Fans, and Spiders at the South Pole

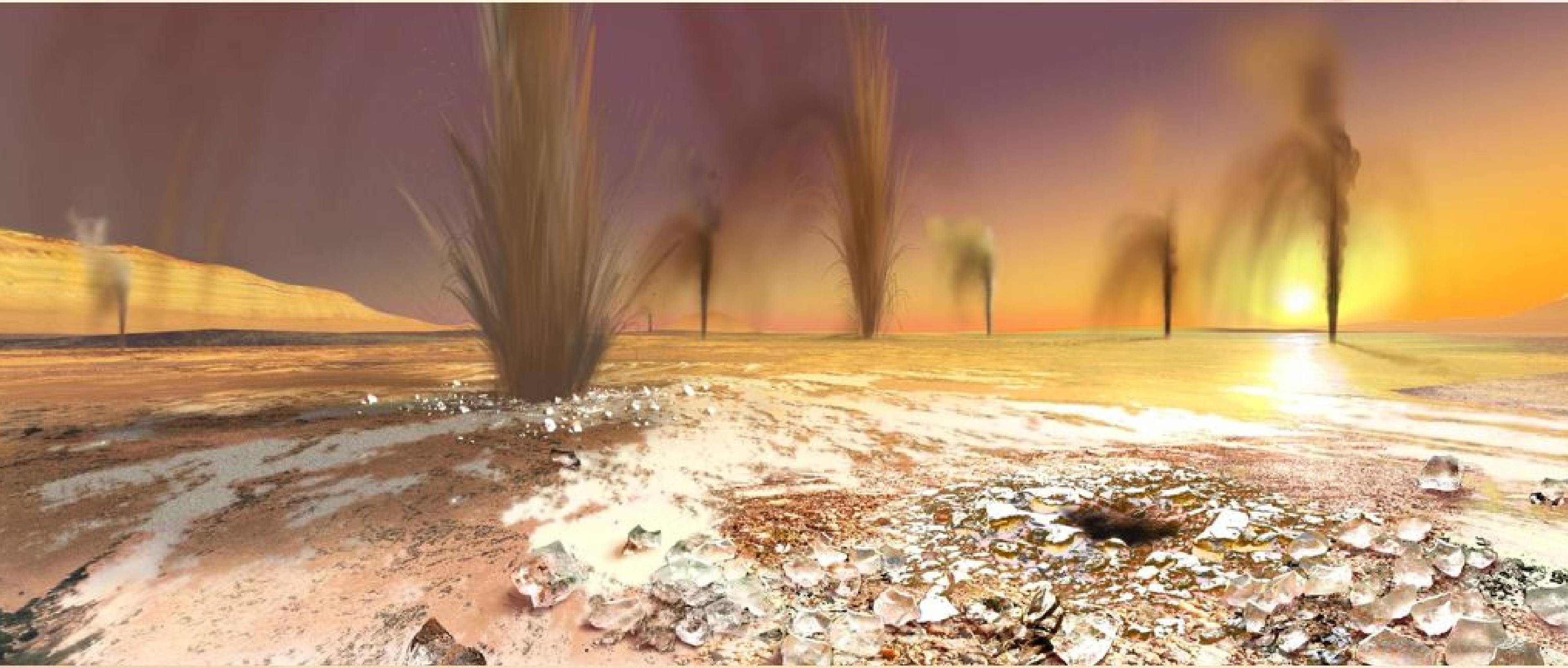






Odyssey

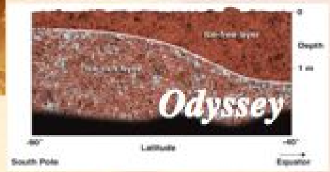
Spots, Fans, and Spiders = CO_2 Geysers



Mars Reconnaissance Orbiter (MRO)-2005

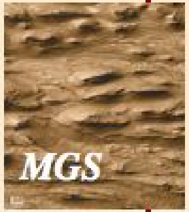
Salient Features

- 4 Earth years in Mars orbit (near polar, 3 p.m., 250 x 315 km)
  - 2 years science observations plus relay support
  - 2 years relay mode with capability to extend science operations
- International Science Payload:
  - Sub-meter (~ 30 cm/pixel) & context (6 m/pixel) imaging
  - Hyperspectral (~20 m, 7 nm) compositional mapping
  - Atmospheric profiling and weather monitoring
  - Radar probing of the near-subsurface; gravity science
- Relay Telecom Payload + Optical Navigation & Ka-Band Experiments
- Launched: August 12, 2005; Arrived: March 10, 2006; Aerobraking: April-August 2006
- Primary Science Phase: Nov. 2006 - Dec. 2008; Relay Phase: May 2008 - Mission End, Dec. 2010



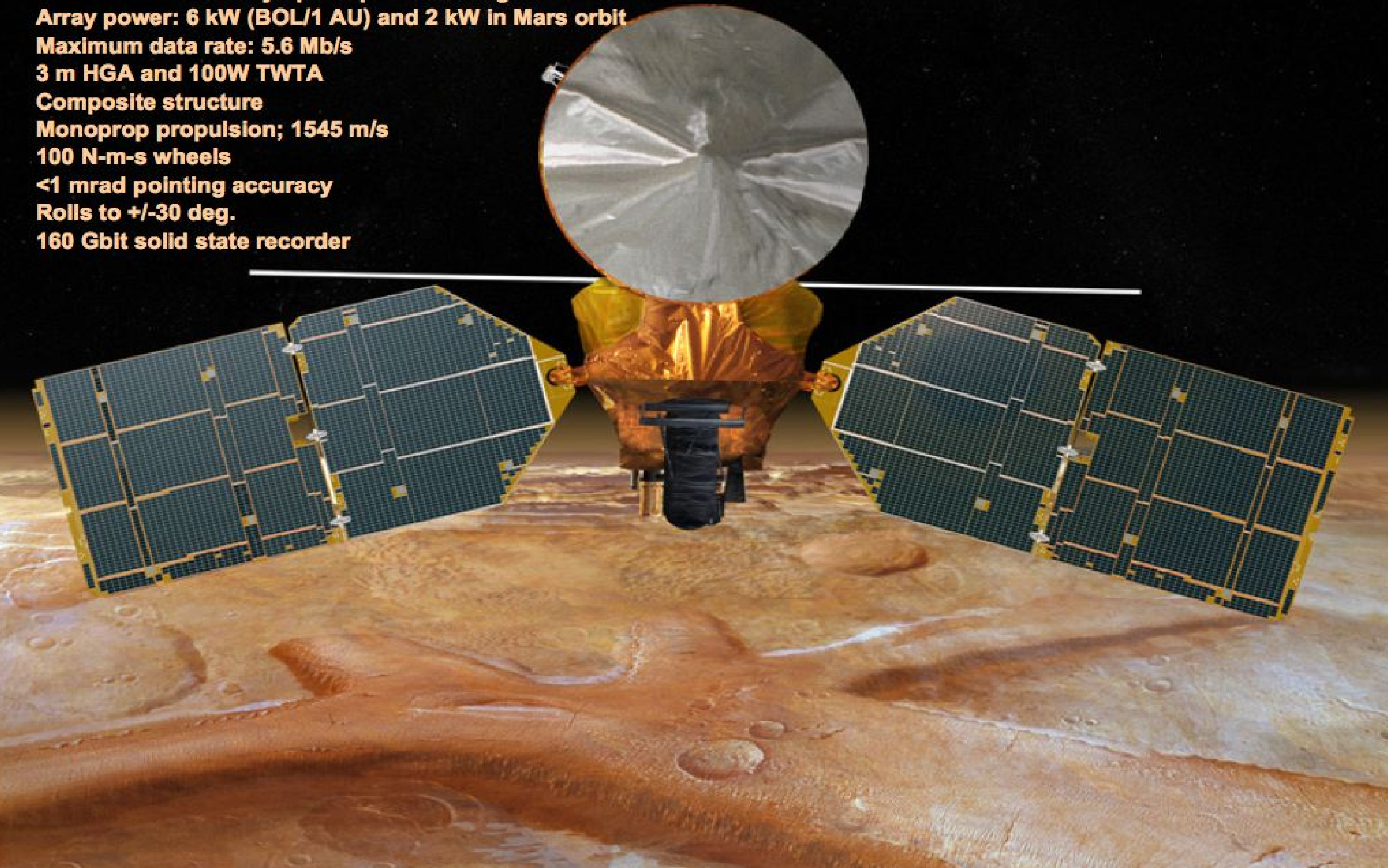
Science: "Follow the Water" Strategy

- Characterize Mars' seasonal cycles and daily variations of water, dust & carbon dioxide.
- Characterize Mars' global atmospheric structure, transport and surface changes.
- Search sites for evidence of aqueous and/or hydrothermal activity.
- Characterize in detail the stratigraphy, geology & composition of Mars surface features.
- Characterize the Martian ice caps and the polar layered terrains.
- Profile the upper crust while probing for subsurface water and ground ice.
- Characterize the Martian gravity field and upper atmosphere in greater detail.
- Identify and characterize many sites for future landed missions.



Spacecraft Description

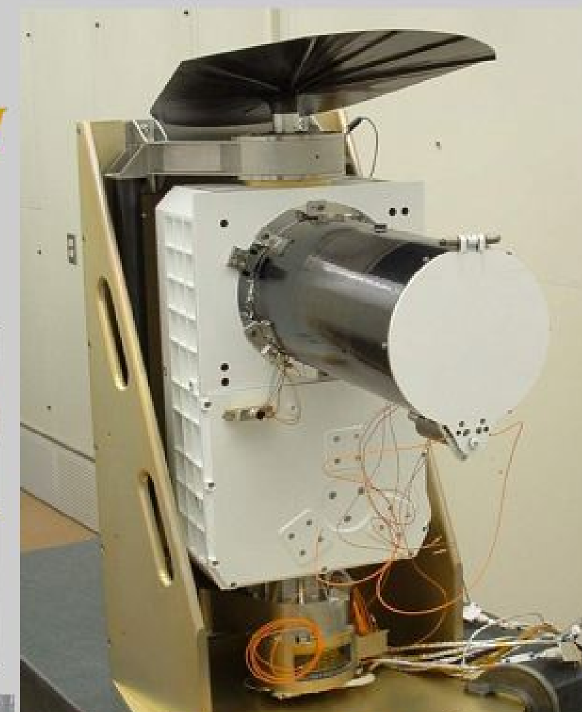
Launch mass: 2180 kg
Size: 14 m solar array tip to tip and 7 m high
Array power: 6 kW (BOL/1 AU) and 2 kW in Mars orbit
Maximum data rate: 5.6 Mb/s
3 m HGA and 100W TWTA
Composite structure
Monoprop propulsion; 1545 m/s
100 N-m-s wheels
<1 mrad pointing accuracy
Rolls to +/-30 deg.
160 Gbit solid state recorder



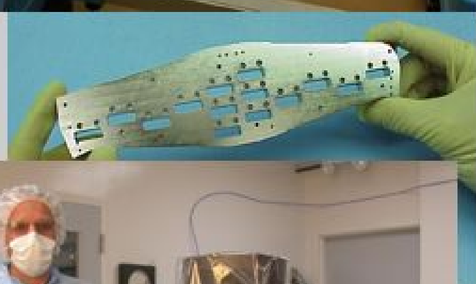
MRO Science Instruments

HiRISE

CRISM



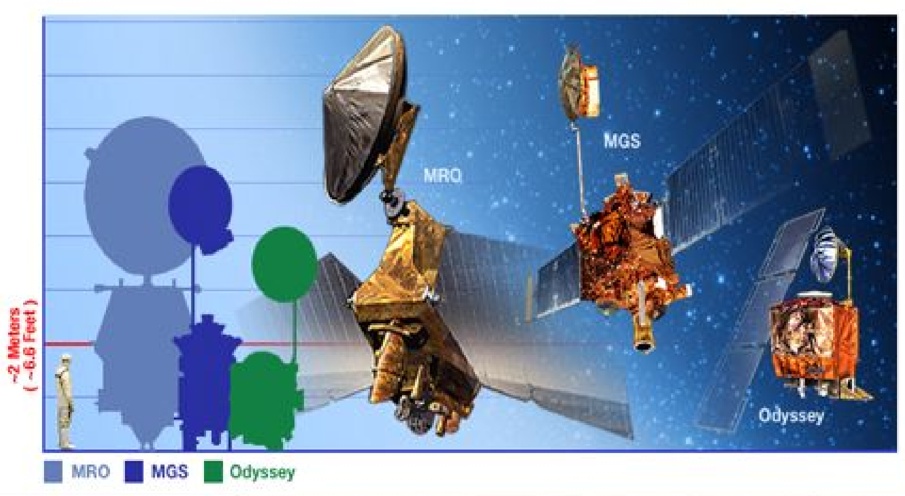
MARCI



MCS

CTX

SHARAD



MRO is *BIG*, by Any Comparison

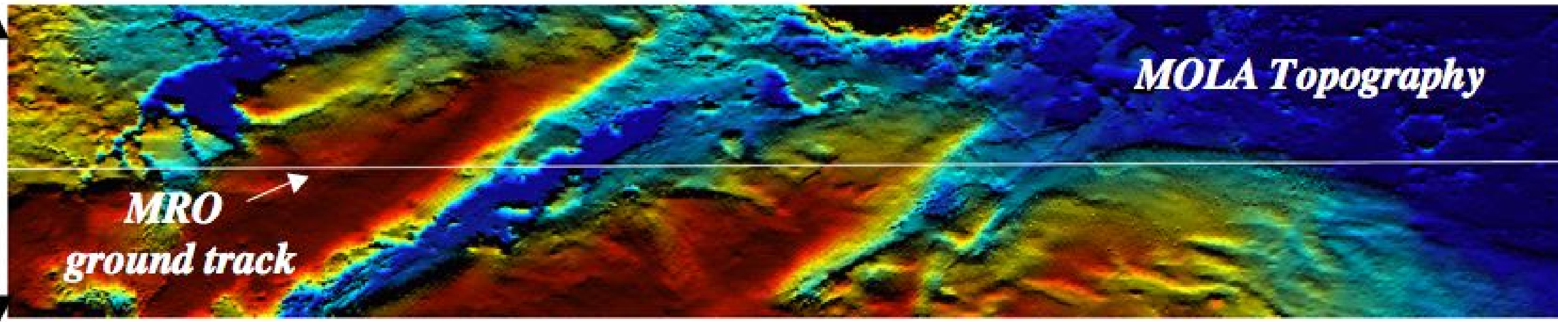
SHARAD Observation of Medusa Fossae On 9/19/2006

WU-SHARPS

SHARAD Post-Deployment Observation — Mars Reconnaissance Orbiter

S

~300 km



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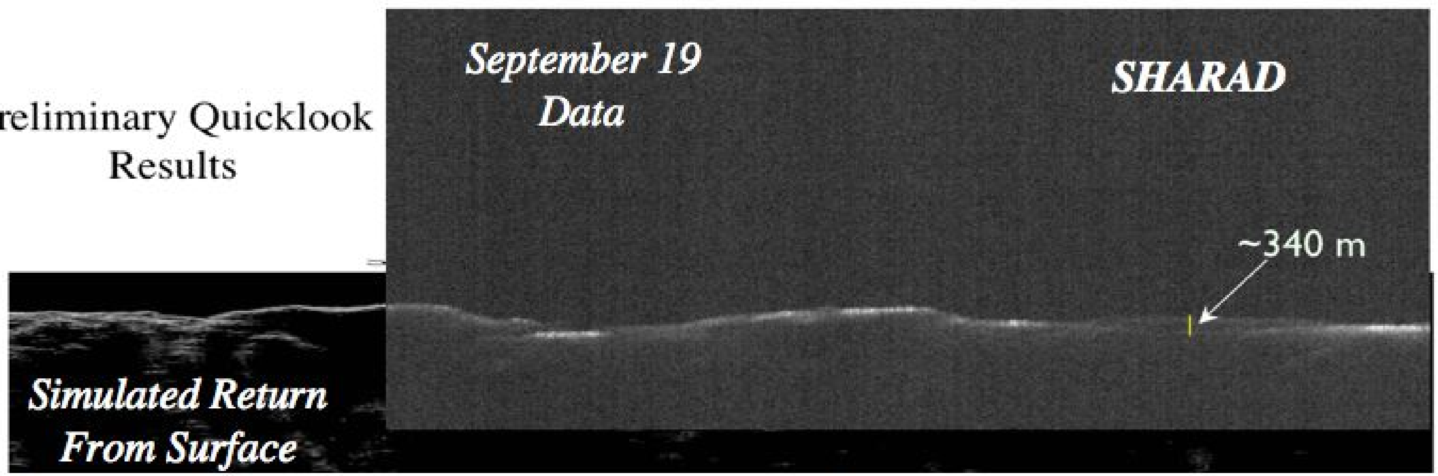
Preliminary Quicklook Results



SHARAD preliminary radar-gram superimposed on simulated radar-gram computed from MOLA topography (top)

Mars Exploration Rovers-2003

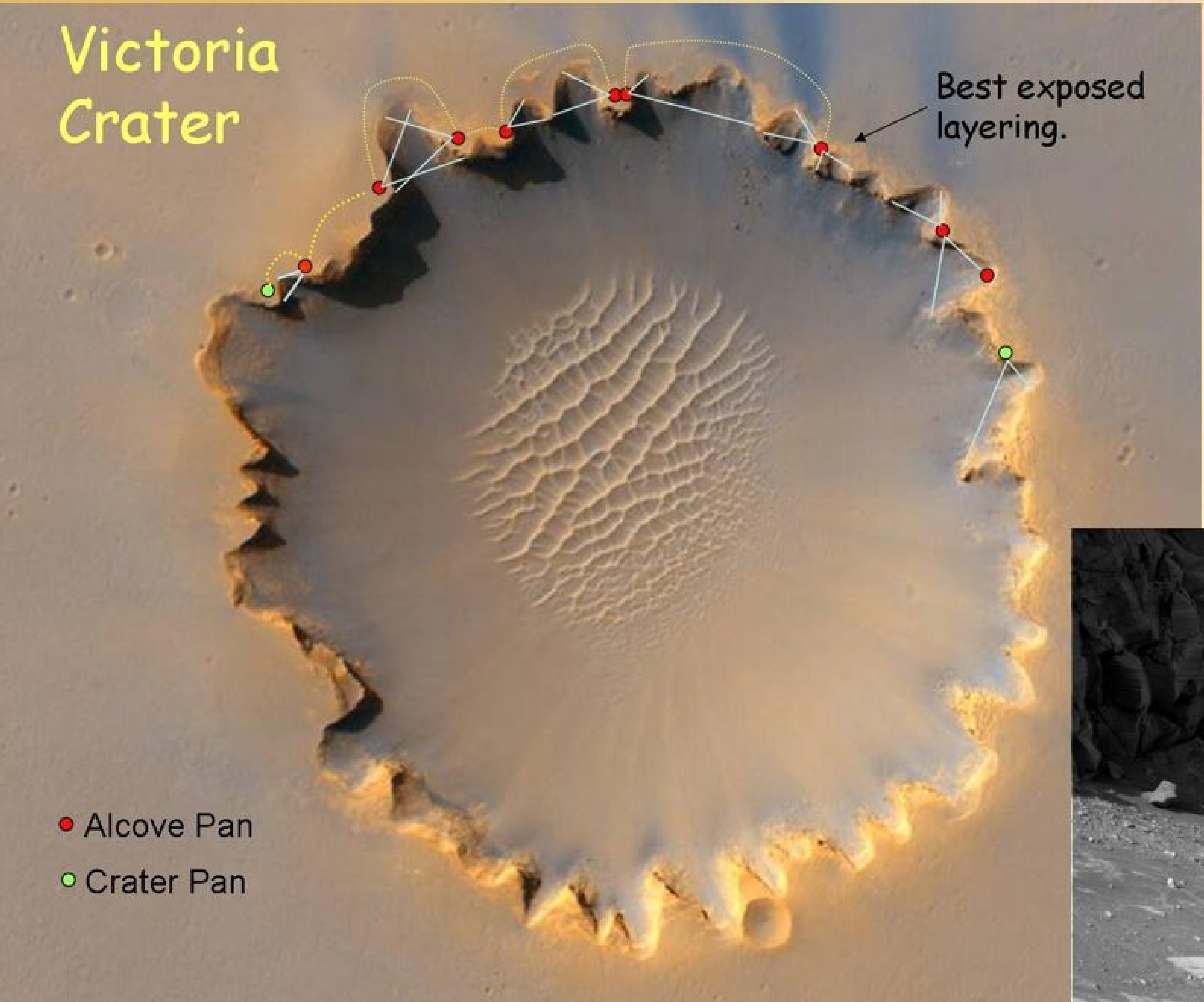
Salient Features

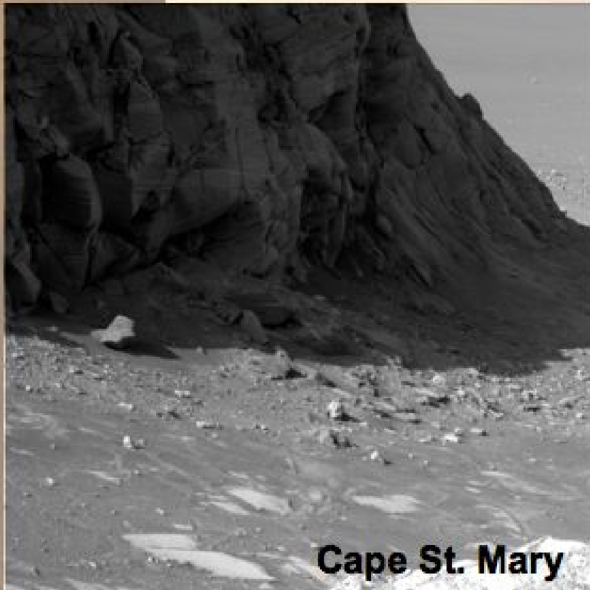
- Two Mars landers launched in June and July of 2003
- Delivered to the surface using the Mars Pathfinder Entry, Descent and Landing system
- 5 instruments to conduct remote and in-situ observations
- Arrived January 2004 at two scientifically distinct sites
- Operational life $\geq$ 90 sols for each lander
- Rover traverse capability $\geq$ 1 km

Science

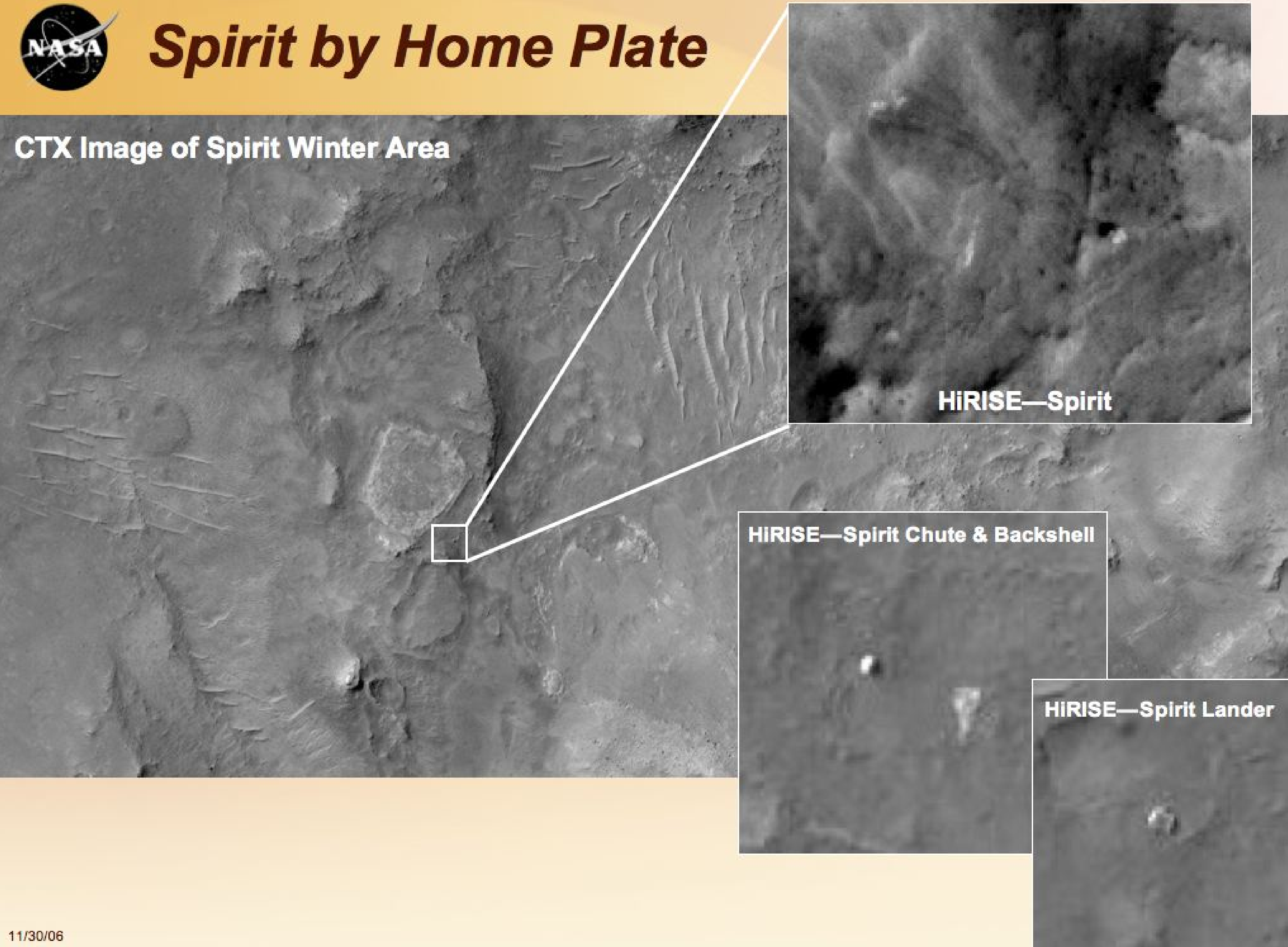
- To determine the aqueous, climatic, and geologic history of a site on Mars where conditions may have been favorable to the preservation of evidence of pre-biotic or biotic processes.
- To identify hydrologic, hydrothermal, and other processes that have operated at the landing site.
- To identify and investigate martian rocks and soils that have the highest possible chance of preserving evidence of ancient environmental conditions and possible pre-biotic or biotic activity.
- To respond to other discoveries associated with rover-based exploration.

Traverse & Imaging Plan





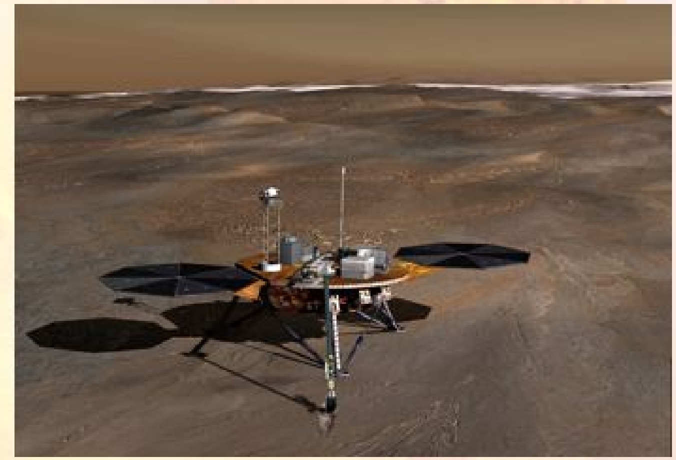
Spirit by Home Plate

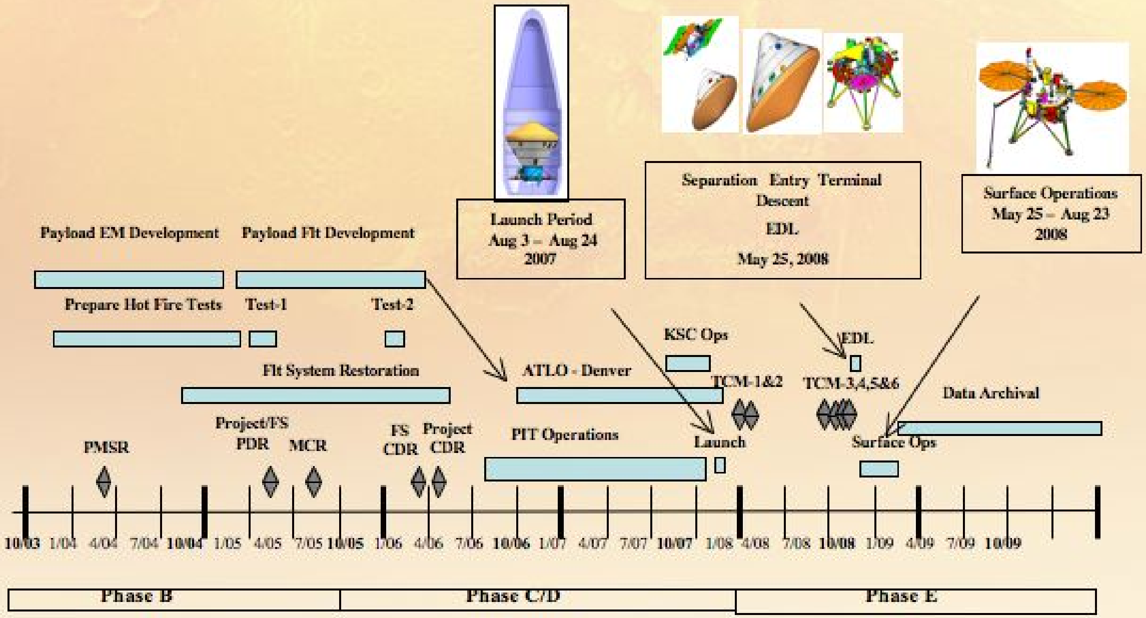


Phoenix-2007

Salient Features

- *90 Sol mission to the water rich northern latitude (~65°-75°) of Mars*
- *Makes use of the flight assets developed for the postponed MSP'01 lander*
- *Two analytical in-situ instruments: Thermal Evolved Gas Analyzer (TEGA), and Microscopy, Electrochemistry & Conductivity Analyzer (MECA)*
- *Both analytical instruments supplied samples of the Martian surface by the robotic arm*
- *Three imagers: Mars Descent Imager (MARDI), Surface Stereo Imager (SSI) and Robotic Arm Camera (RAC)*
- *Meteorological suite to measure Martian winds, temperature, and pressure*

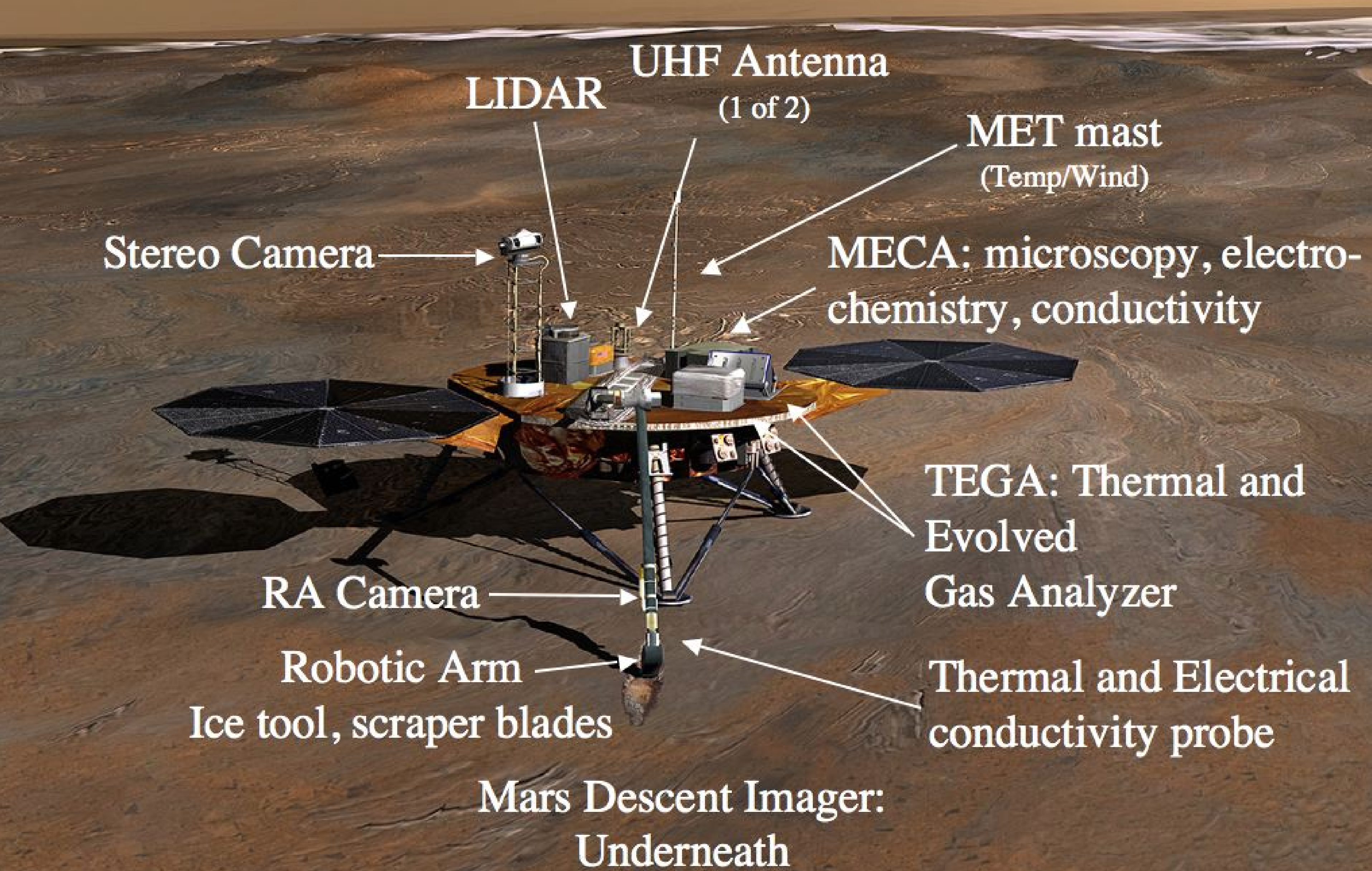




Science

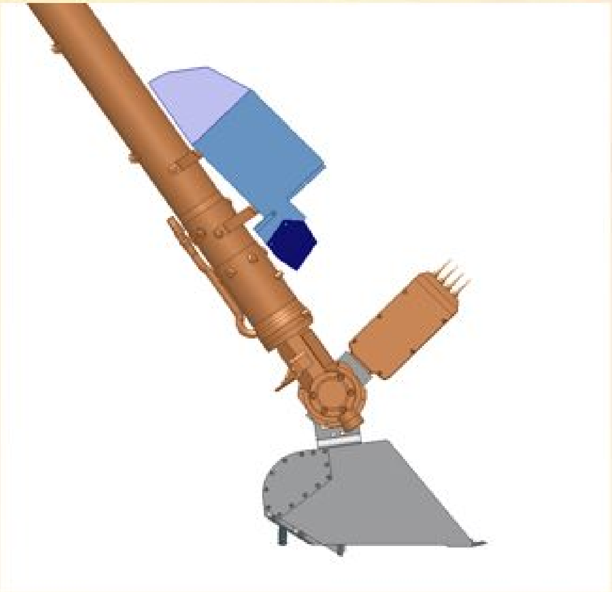
- ***Goal #1:*** ***Study the history of water*** *in all its phases with paleo-hydrological, geological, chemical, and meteorological methods*
- ***Goal #2:*** ***Search for habitable zones*** *by characterizing the subsurface environment in the permafrost region, by measuring the concentration of organic molecules, by performing water chemistry on wet soils (water provided), and by microscopic examination of soil grains*

The Phoenix Lander



Phoenix Will Uncover the History of the Northern Ice

- *The soil mineralogy and chemistry retain signatures that ice has melted and interacted with the soil*
  - *Significant salt content and its inventory of anions and cations tells us whether water ever leached salts from the soils and how it compares with Earth soils*
  - *Carbonate or sulfate mineralogies give important clues to the history of the planet*
  - *The geomorphology of the surface can be compared with earth analogs to try to understand what forces shaped the surface*
  - *Isotopic ratios of hydrogen and oxygen tell us whether the surface ice and the atmospheric water vapor are in equilibrium*



Scientific Goals of the Planned Mars Science Laboratory

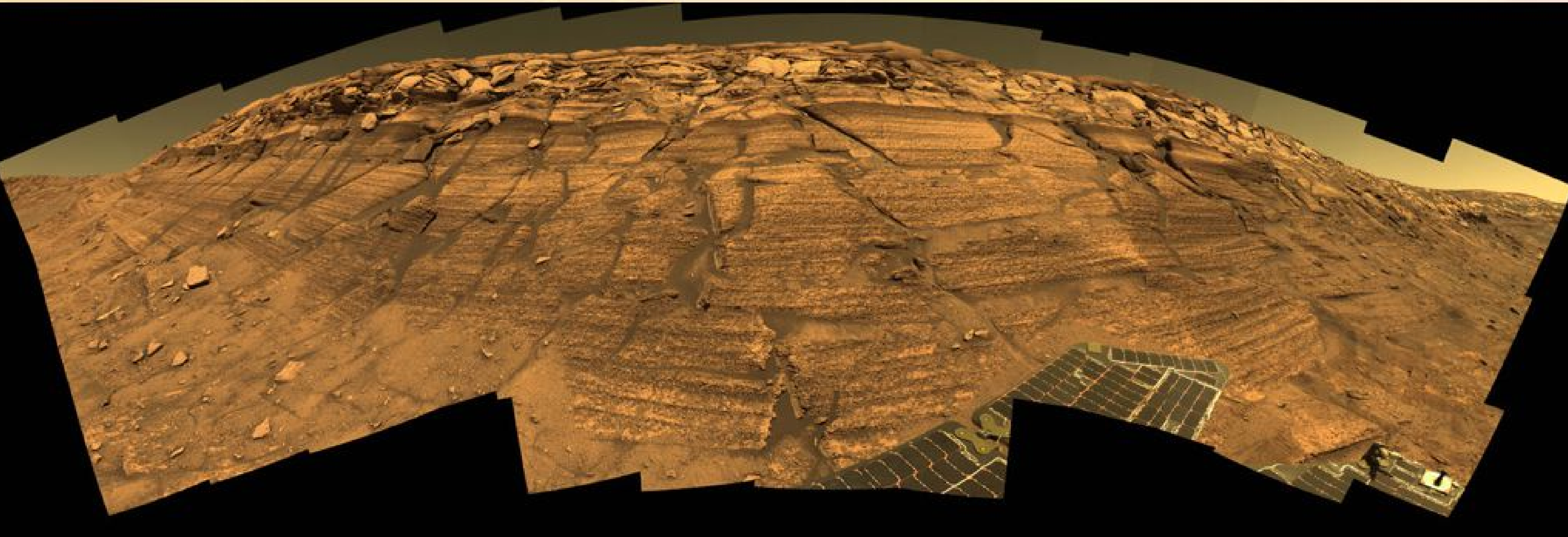
Explore and Quantitatively Assess a Habitable Environment

Habitability and Human Exploration:

- Detect and identify any organic compounds
- Make an inventory of the key chemical building blocks of life
- Identify traces of past life
- Characterize the radiation environment at Mars' surface

Geology and Climate:

- Examine the composition of rocks and soils and interpret the processes that formed and modified them
- Assess how Mars' atmosphere has changed over billions of years
- Determine the current distribution and cycles of water and carbon dioxide



Mars Science Laboratory-2009

Mast Camera (Mastcam)
Color stereo imaging

Chemistry and Camera (ChemCam)
Chemical composition

Rover Environmental Monitoring Station (REMS)
Meteorology and UV

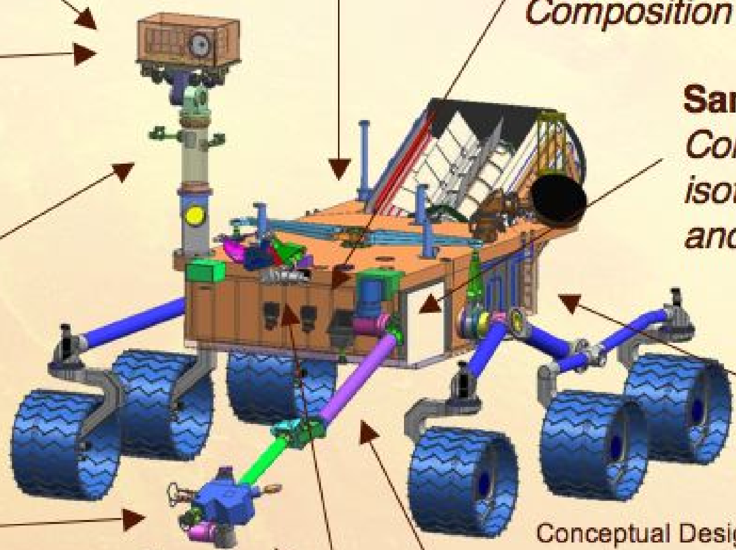
Mars Hand Lens Imager (MAHLI)
Microscopic imaging

Alpha Particle X-Ray Spectrometer (APXS)
Chemical composition

Radiation Assessment Detector (RAD)
Surface radiation

Chemistry and Mineralogy (CheMin)
Composition and mineralogy

Sample Analysis at Mars (SAM)
Composition, organics, and isotopes of samples; composition and isotopes of air



Conceptual Design

Dynamic Albedo of Neutrons (DAN)
Subsurface hydrogen

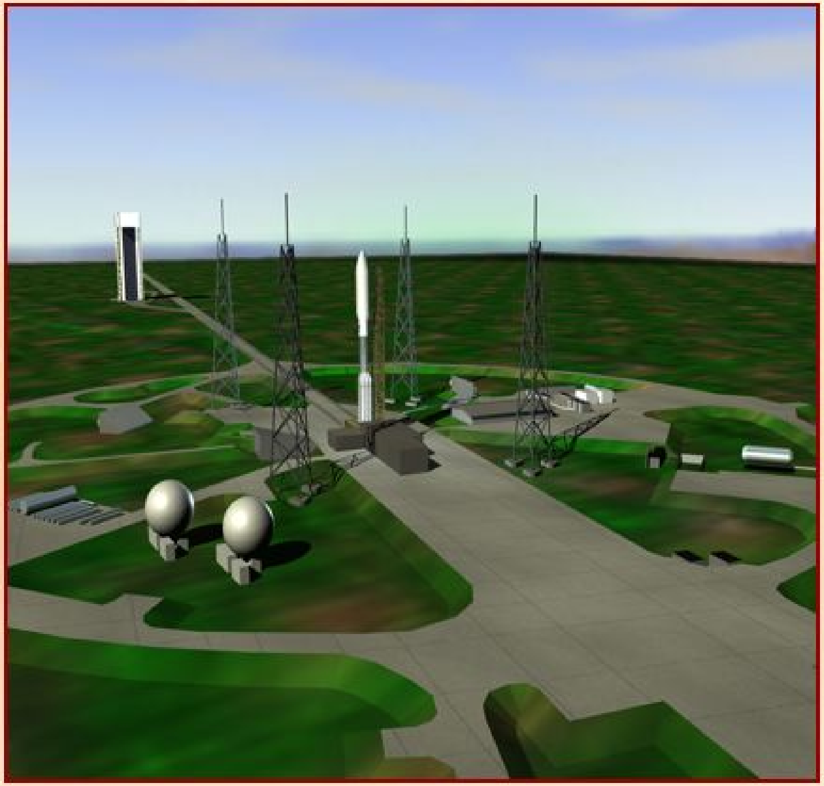
Mars Descent Imager (MARDI)
Descent imagery

Sample Acquisition / Sample Processing and Handling (SA/SPaH)
Scoop, corer, abrader, rock crusher, sample delivery system

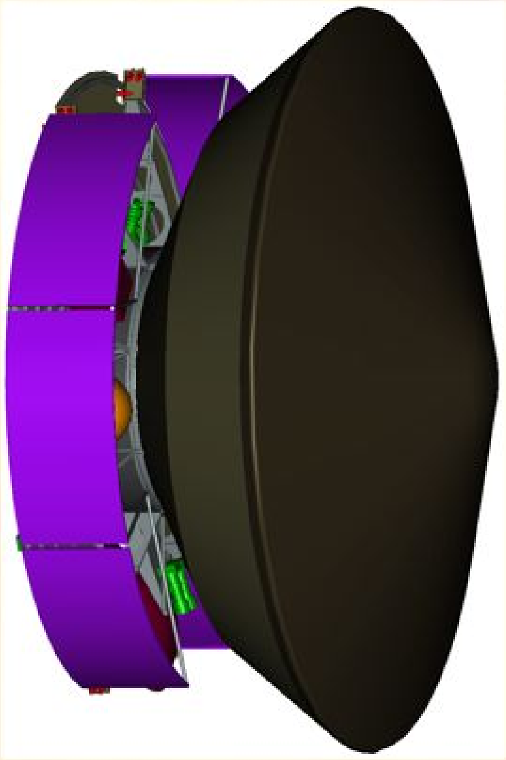
Four types of instruments:
Remote sensing, contact sensing, environmental, analytical laboratory

Launch, Cruise and Approach

Launch
- September – November 2009
- Atlas V launch vehicle

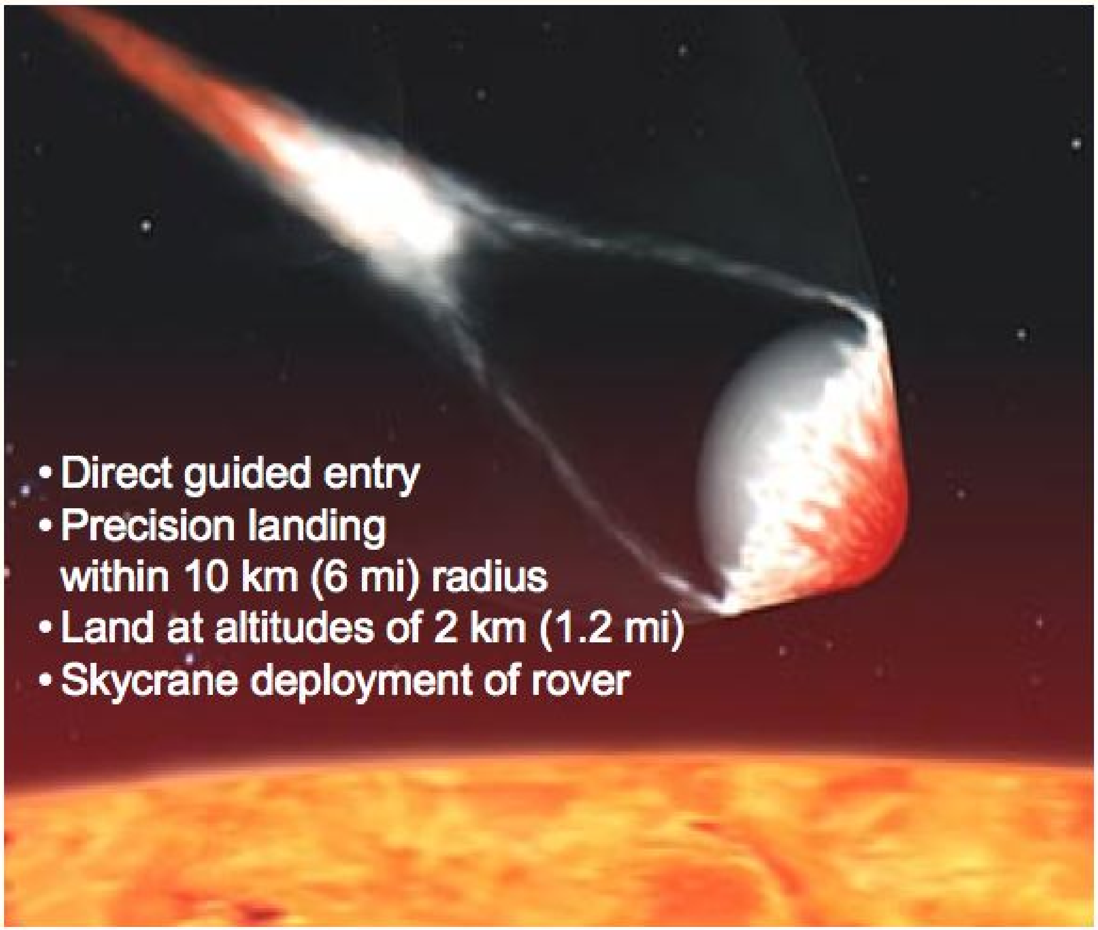


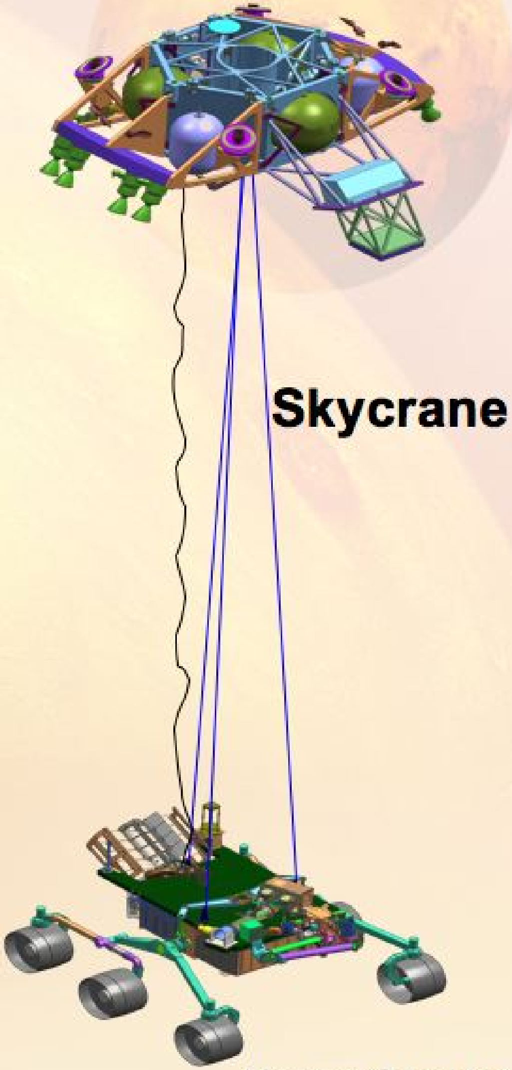
Cruise and Approach
- 10-12 month flight time
- Jettisoned cruise stage



Entry, Descent and Landing

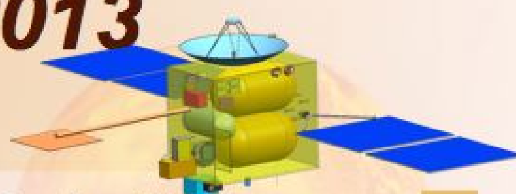
Descent through Mars' atmosphere



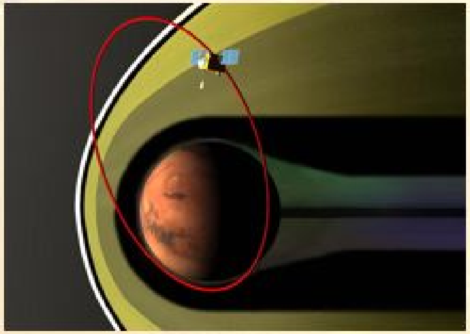


Design Concept

Mars Science Orbiter (MSO)-2013
One Potential Concept



SCIENCE MOTIVATION



Atmosphere as a System

Characterize from ground to solar wind

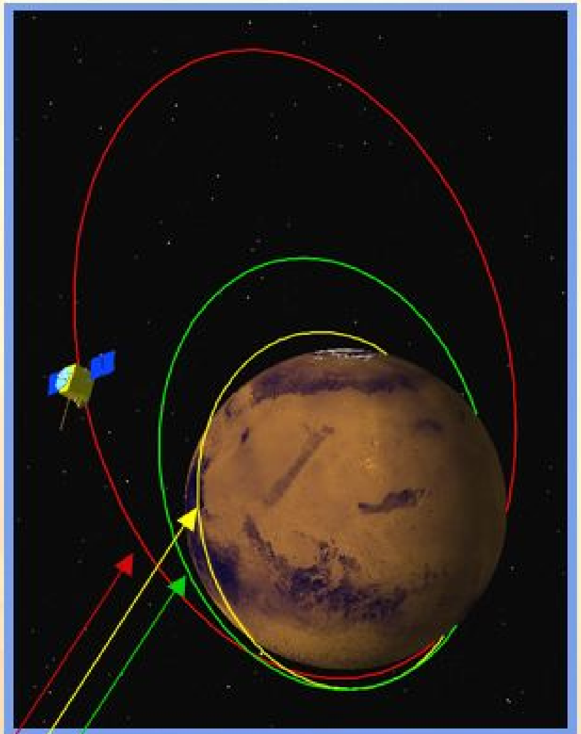
EXAMPLE PAYLOAD

Sub-mm Emission Spectrometer
Fourier Transform Spectrometer
UV Spectrometer
UV-VIS Context Camera
Ion/electron Detector
Ion/neutral Mass Spectr.
Langmuir Probe
Magnetometers
Multi-Freq. Radio Science

Endorsed by SAG

To be finalized by SDT and AO

MISSION DESIGN



Science Phase I 150 X 6500 km
Science Phase II 400 X 400 km
Relay Phase 400 X 2000 km
Science *Emphasis* 2 years
Relay *Emphasis* 8 years
Type II Trajectory, C_3=11.3 km²/s²
Arrival V_∞=3.21 km/s

Pre-Project Orbit Trades

Result: 3 consecutive orbits

FLIGHT SYSTEM

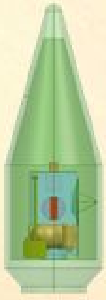
Prominent Features:

- High reliability, 10-year lifetime
- High-performance 10 Gb/day X- & Ka-band telecom
- UHF relay: gimbaled antenna
- Broad-range pointing capability
- Efficient mono-prop propulsion system

MRO-Class Spacecraft

Longer lifetime, higher orbits

MASS SUMMARY



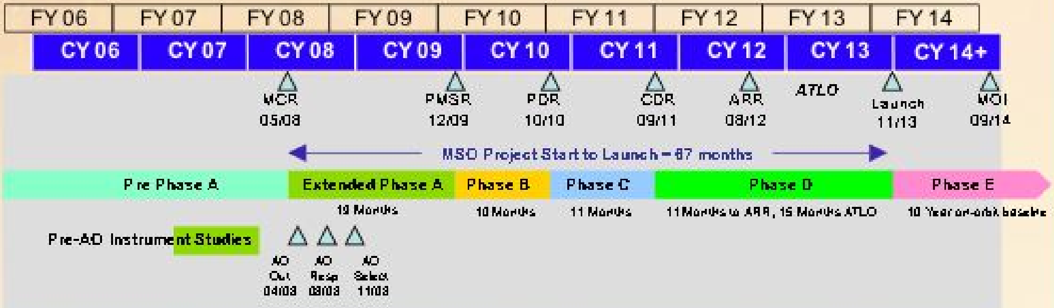
Launch Mass	**3400 (kg)**
(includes contingency)	
Orbiter	1300
Instruments	100
Orbiter Bus	1200
Propellant	2100

4 m Launch Vehicle Fairing

Target Launch Vehicle

High-end Atlas V or Delta IV

MISSION SCHEDULE



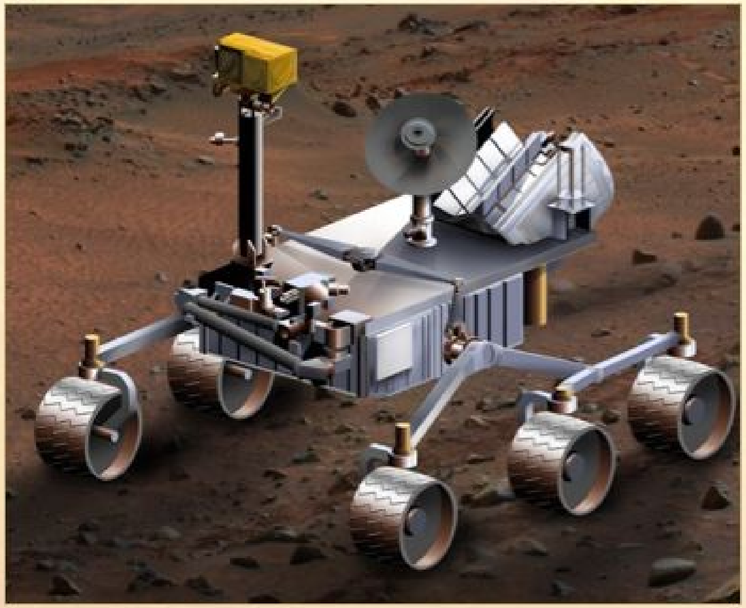
Project Lifecycle

Pre-phase A & Phase A allow for refinement of science and strategic goals

Astrobiology Field Laboratory (MSL Derivative)- 2016, 2018

Objectives:

- *Assess biological potential of sites, interpret paleo-climate record, and search for biosignatures of ancient and modern life*



Issues:

- *Viability of mission depends on MSL results in its search for organics*
  - *Potential for Phoenix to play this role, as well*
- *Planetary protection*

S/C and EDL Heritage:

- MSL

Instrument Heritage:

- *MSL*

Planetary Evolution and Meteorology Network- 2016, 2018

Objectives:

- *Investigate deep interior (elastic constants, density, interfaces)*
- *Meteorology and boundary layer dynamics*
- *Baseline mission: four landers on ≈ 1000 km baseline*

Issues:

- *Qualification of rough landers and instruments*
- *Dispersal of landers*
- *EDL design*
- *Number of successful landers required is 3 or 4?*

Heritage:

- New design for the Lander

Instrument Heritage:

- *Substantial Met package heritage*
- *Substantial US/French development of seismometers*

Mid-Rover-2016, 2018

Function of Mission:

- Explore the geological diversity of Mars by putting down two MER-class rovers for the price of one MSL, with MSL landing reliability and accuracy
- Leverage MSL heritage to the greatest extend possible to realize cost savings

Exploration Metrics:

- Two rovers
- 90-sol primary mission each
- Technology required:
  - Raman, Near-IR instrument development
  - Half-size MSL throttled thrusters
  - Integrated actuators

Payloads:

- Mass
  - Pancam
  - Near-IR imaging spectrometer
- Arm
  - RAT
  - APXS
  - Mössbauer
  - Raman spectrometer
  - Near-IR micro-imaging spectrometer

Technology Heritage:

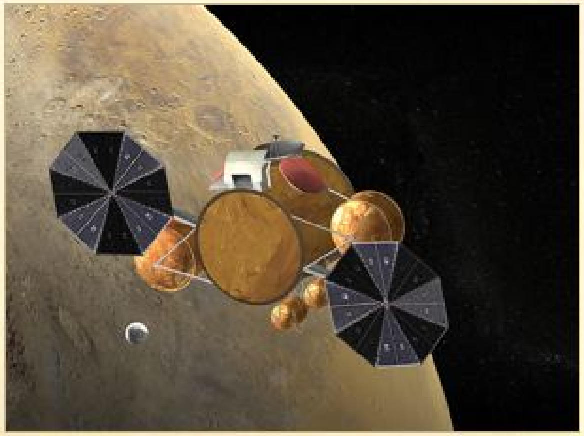
- MSL cruise, EDL, and rover
- MER science instruments

Mars Sample Return-2020's

(Orbiter and Telecom, and Lander, MAV and Rover)

Objectives:

- *Investigate the evolution of the planet and its climate, mineralogy, geochemistry, weathering, and bio-potential*
- *Mobile sample collection*



Orbiter Heritage:

- *MRO*

Issues:

- *Split launch of Orbiter and Lander*
- *Early start for technology and MRSH facility*
- *Relative emphasis on search for evidence of life vs planetary and climate evolution*

Rover Heritage:

- Mid-Rover, MER

Lander/EDL Heritage:

- MSL

Mars Exploration Program
Critical Support Elements

Technology Program—Goals

- *Land greater payload mass at higher altitudes*
- *Place payloads safely and precisely at any desired location on the surface of Mars*
- *Access to sites with terrain too complex to land current rovers*
- *Increase mobility and autonomy of Program spacecraft and enable long-life exploration capabilities*
- *Access the subsurface and acquire samples for in situ analysis*
- *Develop new science instruments*
- *Enable in-situ sample acquisition, preparation, and distribution systems*
- *Develop planetary protection techniques*
- *Develop technologies that enable long-lived science investigation*
- *Develop technologies that enable lower-cost small missions*
- *Develop proximity communication technologies to enable high data return*
- *Develop Mars Sample Return (MSR) technologies*

Base Technology Program Content

The content of Base Technology Program is determined by the longer-term MEP missions. The following technology areas were selected for the 2004 NRA

Technology Area	Current Capability	NRA Goal
Rover Technology	Multiple sols per inst placement Local navigation Wheel odometry	Single sol inst placement Longer range navigation Wheel and visual odometry
Low Cost Mission Technologies Propulsion Solar Cells and Arrays Aerial Mobility	 State-of-the-Art components Non-Mars solar cells, 90 sols Low maturity in aerial inflation, navigation	 10 to 50% reduction in mass ~9% increase in efficiency, 600 sols 120,000 ft validated deployment
Advanced Entry, Descent, and Landing	No spacecraft to spacecraft navigation State-of-the-Art EDL sensors, algorithms No active parachute control	Nav knowledge increase from 5 to1km Order of magnitude in pos, vel, landing 120,000 ft flight tests of active control
Telecom, Navigation, and Tracking	No adaptive data rates, <300 Mbits/sol State-of-the-Art EM modeling, 1 Cray State-of-the-Art transceivers	Adaptive data rates, 520 Mbits/sol Improved algorithms, 1 desktop Order of magnitude better in Kg, W
Subsurface Access	Low TRL technology for Mars drilling 8MM Mars penetration by MER RAT	Develop and demonstrate realistic Shallow (0-1 m) drilling Deep (1-50m) drilling
Planetary Protection	<300 Spores/m^2 Assay of single cultivable spore in 72 hrs No light weight bio-barrier technology	<0.3 Spores/m^2 Single spore assay in 1 hour Develop TRL 6 bio-barrier technology
Mars Instrument Development Project (MIDP)	Instruments developed under PIDDP or other programs (low TRL)	In-situ instruments matured (TRL6) ready for AO proposals

Technologies Infused into Mars Missions

- **MER: 14 Technologies Infused**
  - Power Storage - Lithium-Ion Battery
  - Ground Control Software - Science Activity Planner, Parallel Telemetry Processor
  - Rover Navigation and Control - Long Range Science Rover, Field Integrated Design and Operations Rover, Manipulator Collision, Prevention Software, Visual Odometry, Rover Localization and Mapping, Grid-based Estimation of Surface Traversability Applied to Local Terrain, Automated Instrument Placement, Automated Tracking to Approach Designated Rocks Autonomously, On-Board Global Path Planning
  - Autonomous Science - Autonomous Science to Detect Dust Devils
  - EDL - Descent Image Motion Estimation System

- **MRO: 2 Technologies Infused**
  - Telecom - Electra Payload to TRL 6
  - EDL/Nav - Optical Navigation Camera

Technologies Infused into Mars Missions

- ***Phoenix: 3 Technologies Infused***
  - ***Science -*** *Bio-Barrier Technology, Science Interface Planner, REGA Science Instrument*

- ***MSL : 22 Technology Infusions (not flown yet)***
  - *Science Instruments - SAM/TLS, CHEMIN, LIBS*
  - *EDL - Mars Lander Engine, Radar altimeter/Velocimeter Breadboard, SkyCrane design including touchdown dynamics Testbed, Guided Entry algorithms, Terminal descent algorithms, POST2 (EDL simulation software at (LaRC), DSENDS (SEDL Simulation software at JPL), Aeroshell Aerothermal environment specs and aerodynamic database, TPS database (SLA-561V/SRAM17/SRAM20), Multiple Radial Arm Filter Assembly*
  - *Surface System -TCRE Cold temperature electronics/packaging design rules, Quad-Op-Amps, and Large Sample Characterization for Cold Encoder Parts, Life-tested cruise/surface pumped fluid loops for RTG heat rejection/recirculation systems (HRS), Corer/Abrader Tool (CAT) prototype, decision in progress, Lightweight wheel, differential prototypes, & Touchdown Mobility Research Vehicle (TMRV) design, Surface system simulation tool (MP-AvSIM and ROAMS), Organic cleaning techniques, SA/SPaH concept designs (including results from snake-jaw rock crusher and coring/force-torque sensing evaluations), Next Gen Activity Planning & Sequencing System (GNAPSS) software (including MAESTRO)*
  - *Telecom - Adaptive Electra Data Rate*

Mars Research & Analysis Programs

- **Mars Fundamental Research Program (MFRP)**
  - Basic research on processes relating to the origin, evolution, and habitability of Mars' atmosphere, surface and interior
  - Approximately $7M per year supporting ~100 investigations (note: MDAP & MFRP coordinate funding and selection priorities)

- **Mars Data Analysis Program (MDAP)**
  - Enhance scientific return from missions by broadening scientific participation in analysis of publicly available data and to fund high-priority areas of research that support future missions.
  - Approximately $7M per year supporting ~100 investigations

- **Participating Scientists - mission specific (typically project funded)**
  - Enhance the scientific expertise and breadth of scientific relevance
  - Facilitate mission operations and data analysis
  - Broaden participation of scientific community

- **Call for Proposals**
  - Program elements in ROSES omnibus NASA Research Announcement
  - Available on NSPIRES website at http://nspires.nasaprs.com/external/index.do

Mars Fundamental Research Program (MFRP)

- Purpose: Basic research on processes relating to the origin, evolution, and habitability of Mars' atmosphere, surface and interior
- Examples
  - Theoretical and experimental studies of Mars processes
  - Laboratory and field studies of Mars meteorites and terrestrial analogs
  - Development of datasets for Mars-like materials to aid interpretation of flight data
- Proposal review
  - Due mid summer, full peer review, selection in winter
  - Receive >120 proposals, select ~35%, average award $80K

Mars Data Analysis Program (MDAP)

Funds the analysis of data returned from NASA and other missions to Mars.

Purpose:

A) to enhance mission scientific return
B) broadens scientific participation in the analysis of mission data sets
C) funds high-priority areas of research that support planning for future missions.

Recent Missions:

Mars Pathfinder (MPF)	Mars Global Surveyor (MGS)
Mars Odyssey (MO)	Mars Exploration Rovers (MERs)
Mars Express (MEX)	Mars Reconnaissance Orbiter (MRO)

- *Proposals Received: ~ 100*
- *Selection Rate: 25% - 35%*
- *Average Award Size ~ $70K (2006)*

- Due dates: Usually late summer (August)
- Selections: Usually late winter

Mars Planetary Protection Program

NASA Planetary Protection Policy

- Preserve planetary conditions for future biological and organic constituent exploration

  (prevent Forward Contamination; protect science opportunities)
- Protect the Earth and its' biosphere from adverse effects due to returned samples

  (prevent Backward Contamination)

Required by Article IX of the Outer Space Treaty

Critical Challenges

- Compelling science on Mars requires investigation of regions where Earth organisms might propagate
- Organisms carried on spacecraft could impact future missions and current biological and organic analyses
- Full spacecraft sterilization has not been accomplished by the US since Viking

Technologies and Capabilities

- New sterilization and decontamination methods for future Mars spacecraft
- Better methods to detect and enumerate microbial contamination will improve spacecraft cleanliness
- Knowing which organisms might survive on Mars will enable better detection technologies
- Need better limits on Martian "special regions", where only sterile spacecraft may go

Status

- The Mars Program has a Planetary Protection Manager to handle program-level requirements
- Multiple additional sterilization methods are being evaluated
- Molecular approaches to inventory spacecraft biological contamination are in development
- Mars Program report on Mars "special regions" is under review by COSPAR and ESA

Backup

Program Organization

Associate Administrator for Science* Mission Directorate
M. Cleave

Planetary Science Division Director
J. Green (acting)

Mars Program Financial
S. Black

Mars Exploration Program Director*
D. McCuistion

Mars Program Lead Scientist
M. Meyer

Program Executives
D. Lavery
K. McBride
M. Dahl
R. De Paula

Mars Policy Analyst
G.Tahu

Mars Program Scientists
S. Saunders
C. Niebur
R. Fogel

Headquarters

JPL

JPL MPO Program Manager
F. Li

.... Matrixed from Management & Policy Division

- MEP Director no longer reports directly to AA, per Young Report recommendation

Current International Cooperation

- Mars Global Surveyor (MGS):
  - France: Electron Reflectometer associated with the Magnetometer, Support for the Radio Science Experiment, and provision of the Mars Relay package
  - Austria: Science Support
- Mars Odyssey:
  - Russia: High Energy Neutron Detector (HEND)
  - France: Germanium Detectors for the Gamma-Ray Spectrometer
- Mars Exploration Rovers (MER):
  - Germany: APXS and Mössbauer Spectrometers
  - Denmark: Permanent Magnet Array Experiment
  - France: Science Support
- Mars Reconnaissance Orbiter (MRO):
  - Italy: Shallow Radar (SHARAD)
- ESA Mars Express (MEX):
  - NASA is a participant on each of the 6 instruments through bilateral arrangements, plus the overall mission with ESA

Upcoming International Cooperation

- 2007 Phoenix Lander:
  - Canada: Meteorological Station
  - Germany: Robotic Arm Camera
  - Switzerland: Atomic Force Microscope
  - Denmark: Magnetic Properties Experiment

- 2009 Mars Science Laboratory (MSL):
  - Russia: Dynamic Albedo of Neutrons (DAN) Investigation
  - Canada: Alpha Particle X-Ray Spectrometer (APXS)
  - Spain: Remote Environmental Monitoring Station (REMS) and Communications Hardware
  - France: Contributions to the Chemistry and Micro-Imaging (ChemCam) and Sample Analysis at Mars (SAM) Instrument Suites
  - Germany: Contributions to the Radiation Assessment Detector (RAD)

- 2011 Scout:
  - International contributions are TBD

- 2013 Mars Science Orbiter:
  - International contributions are TBD

Preparing for Human Mars Exploration
Studies to Develop Goal IV

In 2005, extensive studies stemming from "Safe on Mars" resulted in objectives, measurements, and precursor requirements

MEASUREMENTS that would reduce cost, risk, and/or enhance the overall success of future human missions to Mars.

- prioritize and suggest required sequential relationships
- identify where the measurements should be acquired
- suggest the number of distinct sites for each measurement

TECHNOLOGY / INFRASTRUCTURE emplacement that would reduce cost, risk, and/or enhance the overall success of future human missions to Mars.

MISSION ARCHITECTURE that describes in particular the measurement, technology, and infrastructure capabilities of potential testbed missions.

Mars Human Precursor Study

Measurements, Technology, & Infrastructure Results

Early Phase (2011-2016)

Influence architectural decisions for human missions

- Measurement objectives (dust, atmosphere, biohazards, water, etc.)
- Atmosphere/regolith ISRU demos
- Aerocapture (70˚ cone) demo

Mid Phase (2018-2022)

Commitment to architectures for humans

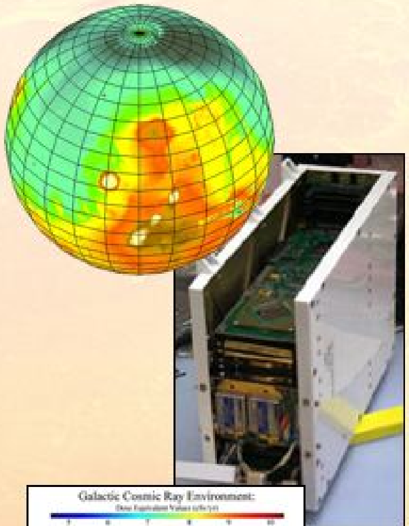
- Subscale demonstration of a human scalable landing system
- Pinpoint Landing
- Subscale demonstration of a human-scalable ISRU surface system
- Radiation shielding properties of regolith
- Connector durability and materials degradation

Late Phase (2024-2028)

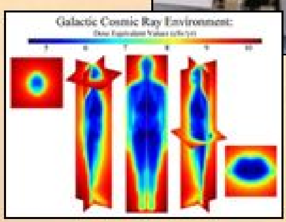
Influence operability decisions & landing site selection

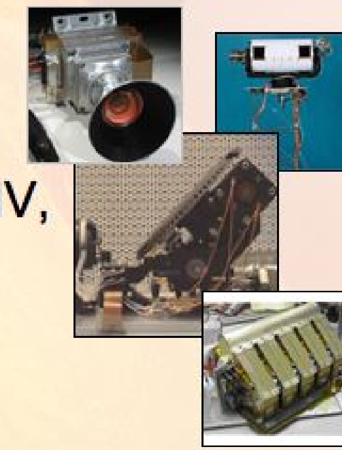
- Detailed surface reconnaissance of a selected first human landing site
- Full-scale "dress rehearsal" of the human mission key systems:
  - Landing
  - ISRU
  - Ascent
- Infrastructure Emplacement e.g:
  - Telecom orbiters
  - Landed infrastructure systems

Preparing for Human Explorers This Decade



Mars Odyssey's Mars Radiation Environment Experiment (MARIE) collected data on the radiation environment (interplanetary cruise & Mars orbit) to help assess potential risks to future human explorers.

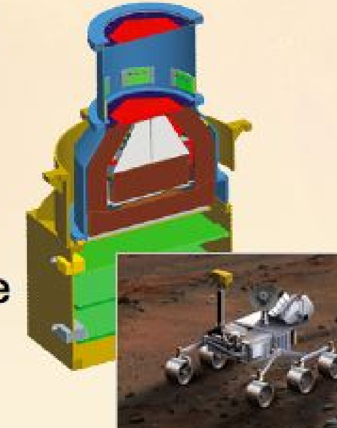




Phoenix's (MECA, TEGA, MARDI, SSI, RA/RAC) payload addresses all of the investigations in Goal IV, with the exception of radiation measurement. The flight system addresses the top two technology demonstrations in Goal IV.

Mars Science Laboratory's Radiation Assessment Detector (RAD) will characterize the radiation environment on the surface of Mars:

- Dose rate and Equivalent Dose rate for humans on the Martian surface
- Validate atmospheric transmission models and radiation transport codes
- Radiation hazard and mutagenic influences to life at and beneath the surface
- Chemical and isotopic effects of energetic particles
- Joint activity with SMD & ESMD



Lunar Exploration Relevancy for Mars

Addressing Humans-to-Mars Challenges, on the Moon

How to develop missions & architectures around known needs, and integrate them into human exploration strategies?

– *Lunar architectures may not automatically address Mars challenges*

Mars Mission Duration

- *Round-trip missions are two to three years in duration*
- *Regenerable systems for water and air*
- *High system reliability and maintainability*
- *Techniques for in-space radiation protection required*

Mars Environment

- *Extensive and routine extra-vehicular activity and surface mobility capability*
- *Water and air regeneration, potentially combined with Mars resource utilization for maintaining reasonable consumables masses*
- *Advanced surface habitation techniques, including dust mitigation, power generation & storage, and thermal control.*
- *Radiation protection on Mars' surface*
- *Planetary protection (forward & backward)*

Operational Experience and Technology Development/Demonstration on the Moon Can Reduce the Risk & Cost of Human Exploration of Mars